URBAN WET-WEATHER FLOWS

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This subject, **Urban Wet-Weather Flows,** was comprised of three basic subareas, i.e., combined-sewer overflows (CSO), sanitary-sewer overflows (SSO), and stormwater discharges. Major conference proceedings related to wet-weather flow (WWF) published during 1999 were: (1) National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments (EPA, 1999); (2) Comprehensive Stormwater & Aquatic Ecosystem Management, Auckland, New Zealand (NZWWA, 1999); (3) the Eighth International Conference on Urban Storm Drainage, Sydney, Australia (Joliffe and Ball, 1999); (4) Water Environment Federation 72nd Annual Conference and Exposition, New Orleans, LA (WEF, 1999); (5) American Society of Civil Engineers 26th Annual Conference, Water Resources Planning and Management, Tempe, Arizona (ASCE, 1999); (6) American Water Resources Association 1999 Annual Water Resources Conference – Watershed Management to Protect Declining Species, Seattle, WA (AWRA, 1999); and (7) New Applications in Modeling Urban Water Systems, Guelph, Canada (James, 1999).

Sullivan and Field (1999) presented an overview of the Environmental Protection Agency's (EPA's) WWF research program, which was expanded in October 1995 with the establishment of the Urban Watershed Management Branch at Edison, New Jersey. Research priorities for 1999 were presented as well as efforts to collaborate with other government organizations and professional societies. Watershed management research at ORD's National Risk Management Research Laboratory (NRMRL) addressed the following question: what effective watershed management strategies were available and how do communities select the most appropriate subset from these to match specific watershed needs? (Borst and O'Shea, 1999). Heaney et al. (1999a) presented the results of a national assessment of research needs in urban WWF management. Three interrelated categories of urban WWF management were discussed: CSO, SSO, and urban stormwater discharges.

CHARACTERIZATION

Rainfall Monitoring and Urban Hydrology

James and Johanson (1999) examined simplified, nondeterministic theories regarding the link between rainfall at the ground surface and the resulting runoff. They showed that linear unit hydrograph theory overlooks the inherent non-linearity in the time dimension of the process. A modified approach, the *initial storage theory* (IST), was therefore proposed and tested in the laboratory. They concluded that the IST was an improvement over the basic unit hydrograph method. Pitt (1999) reports that different drainage design criteria and receiving water use objectives often require the examination of different types of rains for the design of urban drainage systems. These different (and often conflicting) objectives of a stormwater drainage system can be addressed by using distinct portions of the long-term rainfall record. Most of the urban hydrology methods currently used have been successful for large "design" storms, but were inappropriate for use when evaluating many water quality problems.

Rainfall errors and flow forecasting. Kawaguchi et al. (1999) presented a case study of short-term rainfall characteristics that showed considerable changes in rainfall intensity during the past 40 years, where the 20-minute rainfall intensity having a 10-year return period increased by 20 mm/hr. This increase in the design storm characteristics has a profound effect on the performance of urban drainage systems. Fo and Crawford (1999) examined rainfall data having a 2 km x 2 km grid resolution over time intervals of 15, 30, 60, and 120 min. to quantify runoff prediction errors in Oklahoma. They found that the test watershed had an average underestimated rainfall error of about 28 % which resulted in significant prediction errors when modeling stream flows in the Dry Creek watershed in north-central Oklahoma. Fo et al. (1999) further described new forecast systems using high-resolution rainfall data-sets from the WSR-88D radar system, the Oklahoma Mesonet, and the Oklahoma Local Analysis and Prediction System (OLAPS). They found that because of the lag time between the peak in precipitation and the peak in stream-flow in Dry Creek, the greatest impact upon the accuracy of hydrologic forecasts resulted from improvements in analyzing the precipitation data.

Krejcik et al. (1999a, 1999b) described rainfall data monitoring needs for urban drainage design in the Czech Republic. They verified the need for a high-density network of rain gauges for sewer system design and evaluations, especially when using single-event simulations. The need for high-resolution data was not as great when conducting long-term simulations and when preparing statistical evaluations of the modeling results. Willems et al. (1999)

examined intensity/duration/frequency (IDF) relationships for different types of storms and seasons in Belgium. For every re-occurrence time period between 10 min. and 15 days, they identified two separate distributions, one associated with convective thunderstorms and the other with cyclonic/frontal storms.

Nguyen and Nguyen (1999) presented a scaling approach for estimating the distribution of short duration rainfall extremes (e.g., less than 1 hour) from rainfall data having longer durations (e.g., 1 day), using recently developed "scaling" theory. The scaling concept implies that statistical properties of the extreme rainfall processes for different temporal scales were related to each other by a scale-changing operator involving only the scale ratio. Rainfall monitoring with radar. In spite of the highly positive outlook of the obvious benefits, Einfalt and Maul-Kotter (1999) were concerned about the lack of a standard for the use of radar-based precipitation measurements in conjunction with hydrologic models. They described current efforts by the State Environmental Agency in North Rhine-Westphalia, Germany, to investigate the possibilities of developing a standard for radar data use from the German Weather Service for standard hydrological watershed modeling.

Faure et al. (1999) described some limitations for using radar rainfall data to aid sewage system management. They concluded that weather radar seems an important tool in evaluating the spatial structure of rain and in anticipating very short-term changes in precipitation over an urban area. However, the rainfall variability in space and time restricts the accurate forecasting period. In order to quantify the ability of radar data for forecasting, they examined the forecasting range limits for typical urban catchment areas (1 to 180 km^2) in Nancy, France. They found that the limits varied greatly according to the rain conditions, leading them to propose a sewage system management strategy based on predefined management scenarios and real time identification of the type of the rain event. Koishikawa et al. (1999) also examined the application of rainfall radar information for use with operational support systems used for urban drainage facilities. They found that in order to be effective, the radar rainfall data must be collected accurately and with high resolution in both time and space. They demonstrated increases in the accuracies of runoff simulation modeling when adequate radar rainfall data were used. Vivekanandan et al. (1999) studied the influence of terrain on rainfall estimates from radar for a severe storm near Denver, Colorado. Estimates of rain intensities in areas having low or high beam-blockage were compared. They found that specific propagation phase-based quantitative precipitation estimates tend to be less influenced by terrain than reflectivity-based precipitation estimates, as they had hypothesized.

Urban hydrology. Becker et al. (1999a) described the results of detailed field studies investigating lateral flow along different pathways, especially along hillslopes at small catchment scales. Grimmond and Oke (1999) directly measured detailed evapotranspiration mechanisms for urban areas and found that evapotranspiration varied for different land uses and land covers. Hakonson (1999) studied the effects of the burrowing of pocket gophers and vegetative covers on water runoff amounts and erosion losses and resulted in large decreases in runoff and erosion, while vegetation alone slightly decreased runoff but also greatly decreased erosion. Nagasaka and Nakamura (1999) examined the influences of landuse changes on the hydrologic response and the riparian environment in a northern Japanese area. Temporal changes in a hydrological system and riparian ecosystem were examined with reference to landuse conversion in order to clarify the linkages between the two. The results indicated that the hydrological system has been altered since the 1970s, with increasing flood peaks of 1.5-2.5 times and shortening the time of peak flow appearances by 7 hours. The ecological systems were closely related to and distinctly altered by the changes that have occurred in the local landuse.

During studies in Scotland, Soulsby et al. (1999) found that ^{18}O was a useful tracer to indicate the relative influence of spring snowmelt and summer rainfall on stream waters along with their mean residence times. Preliminary estimates of the various waters' residence times in the catchments were < 0.5 year for near-surface soil water and storm runoff, 2.5 years for shallow groundwater, and >5 years for deeper groundwaters. The effects of frozen soil on snowmelt runoff in Vermont were studied by Shanley and Chalmers (1999). The depth of the soil frost varied greatly during the 15 years of observation, with annual maximum frost depths varying from 70 to 390 mm. The enhancement of runoff due to soil frost was most evident on small plots and during extreme events, such as when rain occurred on frozen, snow-free ground.

Quality

Fluxes of total phosphorus (P), total phosphate, and total organic P from seven small watersheds on the Atlantic

Coastal Plain of Maryland for up to 25 years were reported by Correll et al. (1999a, 1999b, 1999c, and 1999d), indicating cropland watershed's P flux were much higher than forested watershed and increased significantly with precipitation. The Bear Brook Watershed in Maine (BBWM) was the sight of a paired watershed study in which the West Bear (WB) catchment was being artificially acidified with 1,800 eq ha^{-1} y^{-1} of $(NH_4)_2SO_4$ resulting in changes in the soil and stream chemistry, while the East Bear (EB) serves as the control (Norton et al., 1999). P chemistry in streams was evaluated at the pair watershed study at the BBWM, indicating the export of Al and P was greater from the treated watershed because the induced acidification was translocating more Al from soils to the streams and the export of P was related to acid-soluble Al particulate material (Roy et al., 1999). One hundred and sixty-two rainfall-induced soil erosion tests were conducted to assist in predicting soil loss and subsequent increase in total suspended solids, indicating soil loss was dependent upon rainfall intensity, and the soil's shear and compressive strength (Liu et al., 1999). After six years of monitoring flow and water quality Jaynes et al. (1999) conclude nitrate appears to be the primary agriculturally related pollutant of concern in Walnut Creek, California thus management practices designed to reduce NO_3 leaching from fields and increase removal within the watershed/stream system should receive primary consideration.

The impact of experimental watershed acidification on xylem cation chemistry was evaluated in eight species at two sites in West Virginia (Clover Run and Fernow) and one site in Maine, BBWM. Experimental watershed acidification or N saturation using applications of $(NH_4)_2SO_4$ equivalent to twice the normal annual wet plus dry N and S deposition caused base cation mobilization followed by depletion that was detectable in sapwood xylem after about 8 yr. of treatment (DeWalle et al., 1999). Water samples were collected from four locations within the Munnell Run Watershed in Mercer County, Pennsylvania, and analyzed for fecal coliforms by MPN and enteric phages by plaque assay using *Salmonella typhimurium WG 49* and *Bacteroides fragiles HSP 40* as hosts. The presence of host specific phages indicate the existence of septic discharges in the watershed, but both fecal coliforms and enteric viruses persist in stream systems, especially during the summer months (Brenner et al., 1999).

Analysis of patterns in pesticide use revealed that concentrations of herbicides and insecticides in agricultural streams, and in most rivers in agricultural regions, were highest in those areas of the nation with the greatest agricultural use. More than 95 % of the samples collected from streams and almost 50 % of samples collected from wells contained at least one pesticide (Gilliom et al., 1999). Sixteen largely agricultural watersheds in the upper portion of the North Bosque River of central Texas were reported by McFarland and Hauck (1999). The proportion of total P (TP) in runoff represented by soluble reactive P (SRP) also increased as the percent of dairy waste application fields above a sampling site increased.

The composition and morphology of colloidal materials entering an urban waterway (Brays Bayou, Houston, Texas) during a storm event was investigated. Analyses of organic carbon, Si, Al, Fe, Cr, Cu, Mn, Zn, Ca, Mg, and Ca were performed on the fraction of materials passing through a 0.45 µm filter. This fraction, traditionally defined as "dissolved", was further fractionated by ultra-centrifugation into colloidal and dissolved fractions (Grout et al., 1999). In the Kerault Region of France, the effects of pollution were studied using solid matter from a section of the A9 motorway. This study analyzed both settled sediments from collecting basin and characteristics of sediments in the water column during and after eight storm events between October 12, 1993, and February 6, 1994. Settled sediments were used to measure particle sizes, mineral content, and related characteristics, whereas water samples were used to document total suspended solids, mineral content, and heavy metals (Andral et al., 1999).

Waters adjacent to the County of Los Angeles, California receive untreated runoff from a series of storm drains year round, in which persons swim there were exposed to these untreated waters. Measures of exposure included distance from the storm drain, selected bacterial indicators (total and fecal coliforms, enterococci, and *Escherichia coli*), and a direct measure of enteric viruses. It was found higher risks of a broad range of symptoms, including both upper respiratory and gastrointestinal, for subjects swimming (a) closer to storm drains, (b) in water with high levels of single bacterial indicators and a low ratio of total to fecal coliforms, and (c) in water where enteric viruses were detected (Haile et al., 1999). Particulate fluxes of aliphatic and aromatic hydrocarbons were measured with a sediment trap moored at 80 m depth offshore of Monaco (200 m water column) during an 18-month period (Raoux et al., 1999). Timperley (1999) described the concepts of chemical bioavailability and its relevance to urban stormwaters and streams.

General. Smullen et al. (1999) compiled stormwater quality data collected from several large sampling programs that have been conducted over the past 20 years. They concluded that it was possible to differentiate stormwater quality based on land use, region of the country, and season. Duke et al. (1999a) examined water quality data for separate storm sewer systems during storm event discharges and during dry weather conditions in the San Francisco Bay Area, California. Long-term mean concentrations for many parameters in most streams were higher during storm discharges than during dry-weather flows.

Particle size/settling. Lloyd and Wong (1999) presented examples of particulate size fraction distributions for road and highway runoff collected in Australia and compared the information with United States and European samples. They found that the particle size distribution of suspended solids in stormwater runoff from roads and highways in Australia were relatively finely graded. Sansalone and Hird (1999), in contrast, found that the particle sizes of stormwater particulates investigated at a freeway site in Cincinnati, Ohio were much larger than typically found elsewhere. In their samples, particles several hundred µm in size were common. They stressed the need to carefully collect stormwater samples for particle size analyses considering the difficulty of representing large particles in samples collected with automatic samplers. Pitt et al. (1999a), during pilot-scale testing of a critical-source-area-treatment device, monitored particle size characteristics both in the influent and effluent. The parking lot stormwater had median particle sizes ranging from 3 to 15 µm. They also monitored particle sizes from 75 source areas in the Birmingham, Alabama, area as part of treatability tests during an earlier phase of this research and found similar small-sized particles. Corsi et al. (1999) measured stormwater particle sizes as part of a treatment system evaluation at a public works yard in Milwaukee, Wisconsin, and found median particle sizes in the influent of about 18 µm.

Andral et al. (1999) analyzed particle sizes and particle settling velocities in stormwater samples collected from eight storm events from the A9 motorway in the Kerault Region of France. They concluded that to effectively treat runoff, particles smaller than 50 µm in diameter (which represented approximately three-quarters of the particulates analyzed, by weight) must be captured. The median particle size for their samples averaged about 15 µm. Settling velocities of these particulates were also studied. The median settling velocities of the particulates smaller than 50 µm ranged from 2.5 to 3.3 m/h, while the larger particles between 50 to 100 µm in diameter had median settling velocities ranging from 5.7 to 13 m/h. Krishnappan et al. (1999) examined particle size distributions of suspended solids in a wet detention pond. They used a submersible laser particle size analyzer that enabled them to examine the particulate characteristics without disturbance by sampling. They found that the suspended solids were mostly composed of flocs, with maximum sizes ranging from 30 (winter) to 212 µm (summer). They concluded that flocs in the size range from 5 to 15 µm would settle faster than both smaller primary particles of higher density, and somewhat larger flocs of lower density. The larger flocs were also found to be susceptible to break up by turbulence.

Toxicity. Love and Woolley (1999) found that stormwater was alarmingly more toxic than treated sewage. The Concord project, funded by EPA, examined the possibility of needed treatment for reuse of residential area stormwater before source area. Runoff from sawmills in British Columbia was monitored for toxicity by Bailey et al. (1999) and found that 42 of the 58 samples were toxic to juvenile rainbow trout. Divalent cations, especially zinc, were the most common source of the toxicity. Tannins and lignins, associated with bulk log handling, were responsible for the remaining toxicity.

Heavy metals. Barbosa and Hvitved-Jacobsen (1999) examined heavy metals in highway runoff in Portugal. Concentrations of Cd and Cr were usually lower than the detection limit (1 µg/L), copper levels were between 1 and 54 µg/L, lead from 1 to 200 µg/L, and zinc from 50 to 1460 µg/L. A lowering of the pH value increased the desorption of previously retained Zn, Cu and Pb from the soil lining the infiltration pond used to treat this water. Barry et al. (1999) identified salinity effects on the partitioning of heavy metals in the stormwater canals entering Port Jackson (Sydney), Australia. Cu, Pb, and Zn was found increasingly in dissolved phases as the salinity increased in the lower sections of the canals. During high flows, most of the metals seemed to be rapidly exported from the estuary as a discrete surface layer, while low flows contributed most of the metals to the estuary. Birch and Taylor (1999) and Birch et al. (1999) also studied the Port Jackson estuary sediments. Historical industrial activity was responsible for much of the contaminated sediments, but atmospheric contributions were also likely important. Stormwater from small catchments, along with sewer overflows, had no observable effects on the distribution of heavy metals in surficial sediments.

Grout et al. (1999) studied the colloidal phases in urban stormwater runoff entering Brays Bayou (Houston, Texas). Colloids in the filtrate after 0.45 µm filtering and further separation by ultracentrifuging, accounted for 79 % of the Al, 85 % of the Fe, 52 % of the Cr, 43 % of the Mn, and 29 % of the Zn present in the filtrates. Changes in the colloidal composition were caused by changes in colloidal morphologies, varying from organic aggregates to diffuse gel-like structures rich in Si, Al, and Fe. Colloids were mostly composed of silica during periods of dry weather flow and at the maximum of the stormwater flow, while carbon dominated the colloidal fraction at the beginning and declining stages of the storm events. Garnaud et al. (1999a) examined the geochemical speciation of particulate metals using sequential extraction procedures for different runoff sources in Paris, France. They found that most metals were bound to acid soluble particulates in the runoff but that copper was almost entirely bound to oxidizable and residual fractions.

Organic toxicants. Fisher et al. (1999) found trace concentrations of dioxins and furans in urban runoff entering Santa Monica Bay, California over a 1-year sampling period. Concentrations of polychlorinated dioxin and polychlorinated furan peaked during storms. The congener and isomer profiles resembled profiles found in lake sediments and rainwater more than they resembled profiles found in urban sources such as dioxins from incinerators or dioxins in contaminated commercial products. Runoff from open land use areas had lower concentrations than runoff from developed land uses. Wenning et al. (1999) studied polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDD/Fs) in stormwater collected from 15 outfalls entering San Francisco Bay, California. Monitoring locations were located both adjacent to and distant from petroleum refineries and included mixed urban/commercial/residential land uses. Few significant differences were found between stormwater in areas adjacent to vs. further from the petroleum refineries. They found that nonindustrialized urban locations may represent important sources of PCDD/Fs to San Francisco Bay.

The environmental fate, chemistry, and toxicity of aircraft deicing compounds (mainly ethylene, propylene, and diethylene glycol) commonly used in Canada was investigated by Kent et al. (1999). Glycols were miscible in water and they were highly mobile. Aerobic biodegradation was the most important environmental fate process affecting glycols in waters and soils. Glycols have relatively low aquatic toxicity, with algae being more sensitive than vertebrates or invertebrates, but the aircraft deicing/anti-icing fluids were more toxic than pure glycols.

Seasonal changes of the herbicides (diuron and simazine) in urban runoff were examined by Revitt et al. (1999a). The herbicide concentrations were higher in storm events, with maximum levels of diuron at 238 µg/L and simazine at 2.2 µg/L recorded. The very high diuron level was during a storm event, which closely followed application of the herbicide. During this event, more than 45 % of the applied diuron was lost to runoff. Qian and Anderson (1999) examined five commonly used herbicides and three pesticides in small streams in the Willamette River Basin, Oregon. Of the variables examined, landuse was the most important for all but one (simazine) of the eight pesticides studied, followed by geographic location, intensity of agriculture activities in the watershed, and the size of the watershed. There were significant differences in the variabilities of the stream concentrations for the urban and agriculture sites. While all 16 nonurban watersheds had significantly higher variations than the urban sites, the same was not necessarily true for the mean concentrations.

CSO. Servais et al. (1999) studied suspended solids, COD, and BOD in CSO affecting the River Seine (France). These basic measurements were compared with values of the biodegradable and refractory fractions of particulate and dissolved organic carbon. They found very similar numeric ratios between these parameters, even in areas having highly different conditions, making it possible for reasonable predictions of the biodegradable and refractory fractions of dissolved and particulate organic matter and of the bacterial biomass in combined sewage. CSO and source area runoff was investigated in Paris (France) by Chebbo et al. (1999). Resuspended material from the sewers contributed a larger fraction of the pollutants (suspended solids, organic matter, copper, and total hydrocarbons) than from the runoff during a runoff event. The results were quite different for lead, zinc, and cadmium whose main source was roof runoff due to corroding roofing materials.

Krebs et al. (1999a) found that the wave front that formed when a significant increase in flow occurred in a combined sewer was composed of the sewage that was present in the sewer before the flow rate increased and not the stormwater component that comprised most of the flow volume. By means of measurements and numerical simulations, they showed that this effect may cause the significant increase of dissolved constituents found in the first flush during CSO events. The vertical (rise) velocity of CSO floatable material, in addition to other basic measurements, was investigated by Cigana et al. (1999) in Montreal (Canada). They found that 80 % of the floatables had a vertical velocity greater than 0.07 m/s.

Solids transport in sewers. Modeling the transport of sediment and other debris in sewers was investigated by Babaeyan-Koopaei et al. (1999). Using correct velocity distributions were found to be critical in order to obtain accurate predictions of sediment transport. A sensitivity analysis investigated the influence of some important parameters involved in the model, especially the drag coefficient, the lift coefficient, solid density, and pipe roughness. Arthur et al. (1999) proposed a new design approach to minimize sedimentation in sewers. They also compared the results of laboratory investigations with real sewer conditions. Johnstone et al. (1999) described on-going research concerning the disposal of large sanitary solids in combined sewers, assessing the relative sustainability of conventional disposal methods using an integrated, holistic approach, incorporating economics, sociology, life cycle data, and a risk assessment. They also described a project designed to study the behavior of the sanitary solids in the sewerage system through laboratory, field, and modeling studies. Skipworth et al. (1999) sampled and analyzed combined sewer sediment deposits and found coarse, loose, granular, predominantly mineral material that was overlain by a mobile, fine-grained cohesive-like sediment deposit in the invert of pipes. The erosion of this more mobile fraction was identified as the major source of the first flush of pollutants associated with CSO events. They presented a new approach to model the erosion and subsequent transport of these mobile sediments.

Rushforth et al. (1999) examined the relationships between the erosion of in-sewer organic deposits and the sediment composition. They found that sewer sediments consist of mixtures of organic and inorganic material and exhibit a much wider range of particle sizes and densities than typically assumed. Specifically, the characteristics of the fine organic sediment found in combined sewer deposits fall outside the applicable range of grain size and density for typically used sediment transport models. Their laboratory experiments showed that the addition of granular material in sewer deposits significantly increases the amount of organic material eroded, compared to a deposit composed entirely of organic material.

In-sewer processes. Haas and Herrmann (1999) examined the problems associated with gas transfer in sewer systems through laboratory and field reaeration studies using volatile tracers and conservative dye tracers. They found that traditional empirical models for reaeration in open channels worked well, with modifications to account for the sewage matrix used instead of clean water. During the field studies in sewer systems having low gas transport rates, concentrations close to the Henry's law equilibrium near the wastewater surface were found to minimize the transfer of the volatile gases from the wastewater to the sewer gas. Huisman et al. (1999) studied oxygen mass transfer and the biofilm respiration rate in sewers. Oxygen transfer mass fluxes were found to be responsible for the major changes to wastewater as it flows to the wastewater treatment plant. They concluded that about 20 % of the dissolved COD could be degraded in the investigated sewer system during the wastewater transport process.

Vollertsen et al. (1999a) measured the effects of temperature and dissolved oxygen (DO) on the kinetics of microbial transformation processes of the suspended sewer sediment particles, suspended wastewater particles, and wastewater. The average Arrhenius constants found for sewer sediment particles and wastewater particles were found to differ significantly from the average Arrhenius constant found for the wastewater. However, no differences for the oxygen saturation coefficients were found between sewer sediment particles, wastewater particles, and wastewater. The anaerobic transformations of wastewater organic solids in sewers were studied by Tanaka and Hvitved-Jacobsen (1999), leading to a aerobic/anaerobic wastewater process model. During 19-25 hours of anaerobic conditions, a net production of readily biodegradable substrate, originating from hydrolyzable substrate, was observed. A small amount of methane production was also observed. Suguira et al. (1999) found that sewage stagnation at the downstream side of a separating tidal weir at a CSO discharge location caused an extraordinary generation of hydrogen sulfide, and associated nuisance odors.

Pollution Sources

Mass balance calculations for a treated and untreated watershed at the BBWM in Main showed that annual and cumulative retention of experimental N amendments has leveled off at about 80 % after nine years of treatment. The annual retention of treatment S has declined to less than 34 % after nine years, with the cumulative retention below 60 % over the course of the experiment (Kahl et al., 1999). Urban runoff samples were collected in a 1- year period in the Santa Monica Bay Watershed during both dry and storm periods and analyzed for polychlorinated dioxins, polychlorinated furans, and polychlorinated naphthalenes (Fisher et al., 1999). Soils that contained high P levels could become a primary source of dissolved reactive P (DRP) in runoff, and thus contribute to acceleration eutrophication of surface waters. Because results might differ on other soils, runoff studies were conducted on three additional Ultisols to identify the most consistent STP method for predicting runoff DRP levels, and determine effects of site hydrology on correlations between STP and runoff DRP concentrations (Pote et al., 1999).

Land applications of organic soil amendments can increase runoff concentrations of metals such as Fe and Zn, metalloids such as B and As, and non-metals such as P and S that have the potential for causing adverse environmental impacts. Aluminum sulfate, or alum $(Al_2(SO_4)_3C(14H_2O)$, can reduce concentrations of some materials in runoff from sites treated with organic amendments (Edwards et al., 1999a). Choi and Blood (1999) reported the increase of urban growth along coastal states, resulting in the growth of urban non-point source nitrogen runoff to be a major contributor to coastal and estuarine enrichment. Hydrologists have known for some time that runoff can occur as the result of both saturation and infiltration excesses in soil containing nonpoint source (NPS) contaminants. Watershed areas that generated NPS polluted runoff needed to be identified prior to the design of basin-wide water quality projects (Endreny and Wood, 1999). Temporal trends of three phenoxyacid herbicides: 2, 4-D, dichlorprop and MCPA and the phenolic herebicide (bromoxynil), were determined in ambient air and precipitation over a 4-yr period within a well-defined watershed in southern Manitoba. Elevated levels of these herbicides in creek water samples were observed during period of high concentration in both atmospheric compartments, despite the lack of surface runoff events within the watershed over that period (Rawn et al., 1999).

Sauer et al. (1999) reported that grazing animal excretions were not as significant a source of nutrients to runoff water as was poultry litter; such treatments receiving poultry litter had significantly higher losses of nutrients, including those most commonly associated with surface water indices. Deicing salt (NaCl) fate was determined from retention and loss in snow cover adjacent to a 14 km section of the highway in southern Ontario during the 1994-1995 winter. Almost all applied NaCl reached the soil surface via direct runoff and infiltration of saline water from the road into the shoulder and right-of-way, and transfer of salt to snow cover adjacent to the highway and release during snow melt (Buttle and Labadia, 1999). Runoff from highways contains significant loads of heavy metals and hydrocarbons, according to German regulations it should be infiltrated over embankments to support groundwater recharge. To investigate the decontaminating effect of greened embankments, soil-monoliths from highways with high traffic densities were taken. Soils were analyzed to characterize the contamination in relation to distance and depth for lead, zinc, copper, cadmium, PAH and MOTH (Dierkes and Geiger, 1999).

Air-water exchange fluxes of 13 polycyclic aromatic hydrocarbons (PAH) were determined along a transect in the Patapsco River from the Inner Harbor of Baltimore, Maryland, to the mainstream of the northern Chesapeake Bay. The direction and magnitude of the daily fluxes of individual PAH were strongly influenced by the wind speed and direction, by the air temperature, and by the highly variable PAH concentrations in the gas and dissolved phases. The largest PAH volatilization fluxes occurred adjacent to the stormwater discharges, driven by elevated dissolved PAH concentrations in surface waters (Bamford et al., 1999). Samples of stormwater runoff from three sawmills on Vancouver Island, British Columbia, Canada, were tested for acute toxicity with juvenile rainbow trout. Causes of toxicity were investigated using toxicity identification evaluation techniques; specifically, treatment with the chelating agent EDTA (Bailey et al., 1999a).

Samples of stormwater runoff from nine sawmills in British Columbia, Canada, were tested for acute toxicity with juvenile rainbow trout over a 23-month period. Toxicity was attributed to divalent cations, particularly zinc, in 32 of the samples. Toxicity in the remaining samples was largely attributed to tannins and lignins and was associated with areas of bulk log handling (Bailey et al., 1999b). Hydrologic runoff was one of the main processes in which radionuclides deposited in the surface environment migrate widely in both particulate and dissolved forms. Amano et al. (1999) concentrated on the transfer capability of long lived Chernobyl radionuclides from surface soil to river water in dissolved forms. Manure or compost from beef cattle feedlots can be an excellent source of nutrients and organic matter when added to soils, but they can also pollute runoff. Eghball and Gilley (1999) determined the effects of simulated rainfall on runoff losses of P and N, and EC and pH following application of manure and compost to a Sharpsburg silty clay loam (fine smectitic, mesic Typic Argiudoll) soil having grain sorghum [Sorghum bicolor (L.) Moench] and winter wheat (Triticum aestivum L.) residues.

A study has been conducted on a 4 % slope during 1991 to 1993 at Belie Mina,, Alabama, on a Decatur silty clay (clayey, kaolinitic, thermic Rhode Paleudult) to determine effects of broiler litter CBL on seasonal transport losses of nutrients and heavy metals in surface water (Wood et al., 1999). Rainfall, slopewash (the erosion of soil particles), surface runoff and fine-litter transport at humid-tropical steepland sites in the Luquillo Experimental Forest, Puerto Rico (18 degrees 20' N, 65 degrees 45' W) were measured from 1991 to 1995 (Larsen et al., 1999). To identify critical sources of P, Sharpley et al. (1999) investigated chemical and hydrologic factors controlling P export from a mixed land use (30 % wooded, 40 % cultivated, 30 % pasture) 39.5 ha watershed in east-central Pennsylvania.

Ecotechnology was the use of technological methods for environmental management in a way to minimize the harm to the environment. Herein the primary contributors to NPS pollution were presented. Best management practices (BMP) for NPS pollution were reviewed, and ecological engineering measures for NPS control were described and evaluated (Dermissi et al., 1999). stormwaters flow directly into the Matajoki River, which was situated in Southern Finland with a catchment area of 24.4 km^2, was monitored with a limnograph. Separate sewage systems were present throughout the catchment area; domestic sewage was directed to a sewage plant directly outside the catchment area. During the research period July 1, 1995 to June 30, 1996, water samples from the Matajoki were taken at least weekly (Olli, 1999).

General. McMahon and Cuffney (1999) described the U.S. Geological Survey's National Water Quality Assessment (NAWQA) Program which was intended to study the relationship between varying levels of urban landuse development in drainage basins and in-stream water quality, as measured by physical, chemical, and biological indicators. These studies were being conducted near Boston (Massachusetts), Salt Lake City (Utah), and Birmingham (Alabama), where rapid urbanization was occurring. Basnyat et al. (1999) described a methodology to assess the relationships between landuse and nitrate and sediment concentrations in streams in the Fish River, Alabama watershed. Residential and other developed urban areas were identified as the largest contributors of nitrate in the area, while active agriculture was identified as the second largest contributor.

Zaman (1999) found that the catchments with high intensities of development in close proximity to stormwater systems were found to be transporting more pollutants to receiving waters than other catchments. Dry-weather water quality monitoring was used to identify the most polluted areas of the catchment. Nirel and Revaclier (1999) used the ratio of dissolved Rb to Sr to identify and quantify the impact of sewage effluents on river quality in Geneva, Switzerland. Rubidium was present in larger quantities than strontium in feces and urine, making the ratio of these two elements represents an effective tracer. This was especially true in regions where the natural Rb/Sr ratio was low (calcareous regions). Gromaire-Mertz et al. (1999) collected stormwater runoff from 4 roofs, 3 courtyards and 6 streets on an experimental catchment in central Paris, France, and analyzed the samples for SS, VSS, COD, BOD_5, hydrocarbons, and heavy metals both in dissolved and particulate fractions. The street runoff showed large SS, COD and hydrocarbon loads, but the roof runoff had high concentrations of heavy metals. Wiese and Scmitt (1999) described urban stormwater contributions into large river systems. Their purpose was to develop a mass balance model for many stormwater pollutants, stressing nitrogen and phosphorus, the oxygen depleting substances and some heavy metals.

Atmospheric. Atasi et al. (1999) used specialized sampling equipment and ultra-clean analytical methodology to quantify the concentrations or fluxes of mercury, cadmium, and polychlorinated biphenyl in ambient air, precipitation, runoff, sanitary sewage, and treated sewage in Detroit, Michigan. Atmospheric deposition was found to be the primary source of the mass of Cd, Hg, and PCB, in runoff from the controlled surfaces. Shiba et al. (1999) also investigated the role of atmospheric deposition as a source of urban runoff contaminants. They found that the chemical substances in rainwater were an important pollution source.

Roof runoff. Foerster (1999) reported on studies investigating roof runoff as stormwater pollutant sources. Runoff samples were taken from an experimental roof system containing five different roofing materials and from house roofs at five different locations in Bayreuth, Germany. It was found that local sources (e.g. PAH from heating systems), dissolution of the roof systems' metal components, and background air pollution were the main sources of the roof-runoff pollution. They found that the first flush from the roofs often was heavily polluted and should be specially treated. They concluded that roofs having metal surfaces should not be connected to infiltration facilities as concentrations of copper and zinc far exceed various toxicity threshold values. They also examined a green (vegetated) roof for comparison. These roofs were found to act as a source of heavy metals which were found to be in complexes with dissolved organic material. Leaching from unprotected zinc sheet surfaces on the green roofs resulted in extremely high zinc concentrations in the runoff. In contrast, the green roofs were a trap for PAH.

Sediment. Benoit et al. (1999a) studied sources of sediment entering Jordan Cove, Connecticut. Recent sediment accumulation rates were found to be decreasing (from 0.84 cm/yr to 0.40 cm/yr) but were slightly faster than relative sea-level rise at this site (0.3 cm/yr). Long Island Sound was found to be an important source of sediment to the cove; a minor part of total sediment was supplied from the local watershed. Benoit et al. (1999b) also studied sources and the history of heavy metal contamination and sediment deposition in Tivoli South Bay, Hudson River, New York. The measured sedimentation rate ranged from 0.59 to 2.9 cm/yr suggesting that rapid accumulation occurred during the time period represented by the length of the cores (approximately the past 50 yrs). The sources of this material were expected to be upland streams, or the Hudson River, during storm events. Concentrations of Pb, Cu and Zn correlated with each other within individual cores at five of the six sites tested, suggesting a common proximate source. Nelson (1999) described the sediment budget of Issaquah Creek, a 144 km^2 mixed-use, urbanizing watershed near Seattle, WA. The water quality of Lake Sammamish, located at the outlet of the basin, was degrading with time, and fine sediment entering the lake from the watershed was a likely source of phosphorus during periods of lakeanoxia. Another potential in-channel concern was the effect of fine sediment on spawning gravel for the salmon species that occupy Issaquah Creek. The sediment balance was being used to identify the major sources of sediment, and thus guide the most effective remedial measures.

Nutrients. Waschbusch et al. (1999) investigated sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin. They collected numerous sheetflow runoff samples from throughout the test watersheds and used SLAMM, an urban stormwater quality model, to quantify the significance of the different phosphorus sources. Lawns and streets were found to be the most significant sources of phosphorus in the test basins, contributing about 80 % of the total annual loading. Peters and Donohue (1999) examined nutrient concentrations and fluxes in tributaries to the Swan-Canning estuary, Western Australia. In addition to the rapid mobility of nutrients in stream water from agricultural areas during the wet season, urban area storm drains typically had high nutrient concentrations, and were also an important source of nutrients to the estuary. Sonoda et al. (1999) described correlations between land use and nutrient inputs to an urbanizing Oregon stream. In the urbanizing areas, possible nutrient sources included fertilizer applied to yards, in addition to roof runoff, various household chemicals, and street runoff.

Litter. Williams and Simmons (1999) investigated the sources of litter in and along the river Taff, South Wales, UK. The greatest inputs of sewage-derived solids were introduced to the river by malfunctioning CSO. While sewage-derived material constituted approximately 23 % of all items on the river Taff, large quantities of waste, especially plastic sheeting, originated from fly tipping sites (illegally dumped rubbish in public places).

Bacteria. Young and Thackston (1999) studied fecal bacteria in urban tributaries in Nashville, Tennessee. The urban streams (unaffected by sewage discharges) were much higher in sewered basins than in nonsewered basins and the fecal bacteria densities were related to the density of housing, population, development, percent impervious area, and apparent domestic animal density. Preliminary fecal bacteria data collected for surface runoff samples in these urban neighborhoods indicated that a relationship existed between various urban land uses and bacterial loading.

Toxicants. Pitt et al. (1999b) investigated typical toxicant concentrations in stormwater, the origins of these toxicants, and storm and landuse factors that influenced these toxicant concentrations. Nine percent of the 87 stormwater source area samples analyzed were considered extremely toxic (using the Microtox™ toxicity screening procedure). Thirty-two percent of the samples exhibited moderate toxicity, while fifty-nine percent of the samples had no evidence of toxicity. Vehicle service and parking area runoff samples had many of the highest observed concentrations of organic toxicants. All metallic toxicants analyzed were found in the analyzed samples. Marsalek and Rochfort (1999) also investigated the toxicity of urban stormwater and CSO. Acute toxicity, chronic toxicity and genotoxicity of stormwater and CSO were studied at 19 urban sampling sites in Ontario, Canada, using a battery of seven bioassays. Most frequent responses of severe toxicity were found in stormwater samples (in 14 % of all samples), particularly those collected on freeways during the winter months. Compared to stormwater, CSO displayed lower acute toxicity (7 % of the samples were moderately toxic, and none of the samples was severely toxic).

Huber and Quigley (1999) studied highway construction and repair materials (e.g. deck sealers, wood preservatives, waste-amended pavement, etc.) for their chemical and toxicological properties and leaching characteristics. *Daphnia magna* (a water flea) and the algae *Selenastrum capricornutum* were used for the toxicity tests. Leaching was evaluated as a function of time using batch tests, flat plate tests and column tests, as appropriate for the end-use of the highway material.

Malmqvist et al. (1999) investigated the sources of pollutants discharging to Lake Trekanten, Stockholm, which receives stormwater from residential and traffic areas. Lead, cadmium, copper, zinc, phosphorus, and PAH in the stormwater from the catchment area were quantified by a source model. It was concluded that building materials were the dominant sources for copper and important sources for zinc. Source control measures, including covering copper-plated roofs, decreasing traffic, and changes of vehicle materials, were expected to reduce discharges of copper to less than a third of current levels.

Potential contributions of urban runoff pollutants to surface sediments of the Passaic River in New Jersey were investigated by Walker et al. (1999). Mass loading calculations demonstrated that urban runoff was a significant source of the metals observed in the sediments, and that PAH and DDT sediment loadings could, in some cases, be accounted for by urban runoff. Observed sediment loads for PCB, however, were significantly higher than were estimated from urban runoff.

Heavy metals. Birch et al. (1999) investigated the sources of heavy metals in stormwater draining into Port Jackson, Sydney, Australia. Road dust from streets with different traffic densities in the catchment were highly enriched with

Cu, Pb, and Zn. Soils also contained high concentrations of these metals over extensive areas of the catchment. Preliminary data suggests that roads and soils were probably important in supplying heavy metals to the estuary but the contributions of atmospheric deposition and contaminated sites had not yet been evaluated.

Garnaud et al. (1999b) studied heavy metal concentrations in dry and wet atmospheric deposits in Paris, France, for comparison with urban runoff. Samples were continuously collected for 2 to 13 months at each of four test sites. Comparisons of median values of metal concentrations showed that rainwater contamination with heavy metals was only slightly higher in the center of Paris than at Fontainebleau (48 km SE of the city) which illustrates the medium range transport of atmospheric contamination.

Sanudo-Wilhelmy and Gill (1999) examined dissolved (< 0.45 µm) trace metals and phosphate concentrations in surface waters collected along the Hudson River estuary, New York, between 1995 and 1997 and compared them with samples collected in the mid-1970s. They concluded that the release of Pb and Hg from watershed soils, and Ni and Cu from estuarine sediments, may represent the primary contemporary sources of these metals to the estuary.

Mercury. Bonzongo et al. (1999) studied the impacts of land use and physicochemical settings on methyl mercury levels in the Mobile-Alabama River system. In the Coastal Plain portion of the state, Hg concentrations above the FDA's safe limit have been found in tissues of some fish species in both Fish River and Mobile Bay, Alabama. These rivers/streams receive most of their Hg from NPS (e.g. atmospheric deposition and inputs related to land use within the watersheds). They reported results of detailed investigations aimed to study the biogeochemistry of Hg and other trace metals, specifically the impact of different land-use types within the watersheds on Hg speciation. Glass and Sorensen (1999) examined a six-year trend (1990-1995) of wet mercury deposition in the Upper Midwest of the United States. The annual wet mercury deposition averaged 7.4 µg Hg/m^2-yr and showed significant variations between sites and illustrated significant increasing trends over the monitoring period. Warm (rain) season wet mercury deposition was found to average 77 % of total annual wet deposition.

Lead. Davis and Burns (1999) examined lead concentrations in runoff from painted surfaces. In many tests, high lead concentrations were found (using 100 mL of wash water over 1600 cm^2 of surface). Lead concentrations from 169 different structures followed the following order (median concentrations in the wash water): wood (49 µg/L) > brick (16 µg/L) > block (8.0 µg/L). Lead concentration depended strongly on paint age and condition, with the lead levels from washes of older paints being much higher than from freshly painted surfaces. Lead from surface washes were found to be 70 %, or greater, in particulate lead form, suggesting the release of lead pigments from the weathered paints.

Platinum. Schaefer et al. (1999) studied the increasing concentrations of Pt, Rh, and Pd in urban areas associated with increased use of catalytic converters on automobiles. At a typical urban site, the daily deposition rate of Pt in airborne dust was up to 23 ng/m^2.

Cadmium. van Geen and Luoma (1999) conducted a five-year study of dissolved Cd in San Francisco Bay, California and adjacent coastal waters. They showed that the composition of surface waters towards the mouth of the estuary was determined largely by the effect of coastal upwelling. However, surface samples collected throughout San Francisco Bay confirmed an internal Cd source unrelated to river discharge. The Cd content of a benthic foraminifer (*Elphidiella hannai*) in a dated sediment core from San Francisco Bay was measured to determine if the water column Cd enrichments in San Francisco Bay could be related to the rapid development of the watershed.

Cyanide. Paschka et al. (1999) studied the water-quality effects associated with the extensive use of water-soluble iron cyanide compounds used as anticaking agents in road salt. Although available information did not indicate a widespread problem, it was also clear that the water-quality effects of cyanide in road salt had not been adequately examined.

Organic toxicants. Ashley and Baker (1999) developed inventories and identified sources for hydrophobic organic contaminants (HOC) in the surficial sediments of Baltimore Harbor, Maryland. There was enormous spatial variability in the concentrations of HOC at the 80 sampling sites which was not well correlated to grain size or organic carbon content, suggesting that nonequilibrium partitioning and/or proximity to sources were important factors. High concentrations of HOC were localized around major urban stormwater outfalls. Lower molecular weight PAH, having lower affinity for particles, may travel further from the sources. Ollivon et al. (1999) studied the PAH fluctuations in rivers near Paris (France). During storm events, the atmospheric contributions of PAH were negligible, compared to stormwater discharges. During heavy rains affecting the river Seine, high first flush PAH concentrations were observed, and about 25 % of the PAH came from the rain and about 75 % came from the stormwater. During light rains, atmospheric contributions only accounted for about 2 % of the total PAH to the river.

Herbicides. Farrugia et al. (1999) studied household herbicide use. They found that typical urban uses of herbicides exceeded agricultural uses, and the transfer coefficients (amount of the herbicide in the runoff compared to the amount applied) was also higher in urban areas. The highest measured diuron concentration was 20 µg/L, while the average was 5 µg/L. Compared to EEC standards for drinking water protection (0.1 µg/L), they concluded that suburban uses of herbicides may severely endanger drinking water supplies.

Monitoring

Buried mineral soil-bags and natural solutions, studied as indicators of forest response to elevated N and S inputs at the BBWM, were reported by Fernandez et al. (1999) having continued utility in environmental monitoring and assessment research. In the Mediterranean region, climatological factors make CSO a major urban pollution problem that should be monitored and controlled. In comparing rainfall estimates from weather radar pictures to a rain-gauge network in terms of the ability to predict sewer flow in the urban basin in Barcelona, Spain, the results showed that the use of radar data enabled the combined sewer system model to improve the reproduction of the observed flows. Also indicating the spatial description of rainfall was a key problem in modeling the events giving rise to CSO (Sempre-Torres et al., 1999).

Atmospheric deposition, often contaminated to varying degrees, can be a significant source of phosphorus to South Florida's aquatic system. Outliers were detected by field notes, derived from visual inspection of the samples, and statistics, based on simple linear regression used for additional screening. Based on detected outliers in the data from 115 monitoring sites, a lumped cutoff value, used for further quality control, of 130 Fg/L was determined (Ahn, 1999). A receiving water quality monitoring program was developed to measure beneficial use impacts resulting from toxicity in stormwater runoff. The goals of the water quality monitoring program were to determine the persistence, fate and significance of the aquatic toxicity in the receiving water (Taylor, 1999).

When considering urban runoff toxicity, it was necessary to carefully consider magnitude, duration, and frequency in any toxicity analysis. First, to measure this toxicity it was necessary to apply a new paradigm, the time-scale toxicity paradigm. The time-scale toxicity paradigm was reviewed, and data from storm events was provided to illustrate paradigm utility in assessing the toxicity of urban runoff and the related impact of urban runoff on receiving systems (Herricks, 1999). A number of stream restoration efforts have been carried out in small watersheds in Maryland for the past ten years. The goal of virtually all of the restoration projects was to reduce high sediment supply from bank and bed erosion and to increase sediment transport, thus restoring a condition of equilibrium between sediment supply and sediment transport. Clar et al. (1999) described the current approach adopted by Baltimore County, Maryland to integrate stream stability assessment and water quality modeling for a comprehensive study of the Patapsco River Watershed in south-western Baltimore County.

The 1996 handbook *Environmental Indicators to Assess Stormwater Control Programs and Practices* described the use of 26 indicators within 6 general categories B water quality, physical/hydrological, biological, social, programmatic and site-specific B to measure the success of stormwater programs. The handbook also suggests a methodology for using the indicators to identify problems within local watersheds and for assessing, re-evaluating and improving stormwater management programs. With grant assistance from the Water Environment Research Foundation, the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) was demonstrating this methodology at a watershed scale (Coyote Creek watershed, Santa Clara County, California) and at a smaller, more defined scale, that of a 28-acre industrial catchment in the City of Santa Clara, California (Cloak and Bicknell, 1999).

A new settling testing method was compared to a traditional test in a laboratory side-by-side evaluation. The comparison attempted to determine whether these tests can capture the rapidly settling particles in wet-weather flow. A summary of the performance, as measured by predicted percent removal of the columns for 15 laboratory bench-scale tests, and the limitations and advantages of each approach were presented and compared (O'Connor et al., 1999). Kuo et al. (1999) presented results of field tests of pollutant removal efficiencies of grassed swales conducted in Taiwan and Virginia. The Virginia experiments tested a highway median swale, while the Taiwan experiments were conducted on an agricultural test farm.

The specific goals of the Small Business Innovation Research (SBIR) project, sponsored by the Federal Highway Administration (FHWA), was to develop a small, inexpensive, simple, effective sheetflow sampler to aid transportation officials in meeting their regulatory requirements. The field testing program includes the installation of approximately 18 samplers throughout varying highway environments in Virginia, Maryland, and California. Stormwater samples will be collected and analyzed for various highway pollutants over a period of 9 months (Graziano et al., 1999).

Several field and laboratory assays were employed below an urban storm sewer outfall to define the relationship between stormwater runoff and contaminant effects. Specifically, two bioassays that measure feeding rate as a toxicological endpoint were employed in the field and in the laboratory, along with bioassays measuring survival and growth of test organisms. The results of the study suggest significant toxicity at this site was due to accumulation of contaminants in the sediment and the mobilization of these contaminants during a storm event (Hatch and Burton, 1999).

Brent and Herricks (1999) proposed a testing protocol for the toxicity assessment of wet weather events that includes an event-focused toxicity test method, a corresponding test metric that more accurately represents the toxicity of brief exposures, and an event-based index that described the acute toxicity of wet weather events. This testing protocol was designed to quantify toxic response produced by brief contaminant exposures (< 24 h), as well as time-varying contaminant exposures, which were typical of wet weather events. The protocol described the use of an event-focused toxicity test to determine a PELET50 (post-exposure lethal exposure time for 50 % of the population) metric for individual event samples.

According to Klove and Bengtsson (1999) the hydrology of a cutover fen was studied from May to October in 1995 and 1996. Rainfall equivalent depths were measured every 15 min and stream runoff was continuously monitored. Storm runoff was separated into different components; rain falling directly into channels and rapid groundwater response based on a contributing area method and on different electrical conductivities of rain-, ground- and stream-water. The Ohio Environmental Protection Agency employed biological, chemical, and physical monitoring and assessment techniques to assess how effectively they were achieving their goals of the Clean Water Act, namely the maintenance and restoration of biological integrity and the basic intent of water quality standards (Yonder et al., 1999). Strecker (1999a) described some of the problems with typical BMP monitoring and effectiveness reporting; and suggested the utilization of consistent stormwater monitoring techniques.

Flow measurement. Burrows et al. (1999) evaluated a flow stick with inclination transducer. The data from the flow stick, when combined with a depth measure, provided an accurate measure of the instantaneous flow rate in a storm, sanitary or combined sewer. Goyen and O'Loughlin (1999) described their project in which they used intra-catchment gauging stations in Canberra, Australia to collect data regarding rainfall and runoff. They determined that the spatial and temporal variability of rainfall and runoff even over a single catchment were great enough to ensure the single-parameter models cannot perform well consistently and so, they proposed a runoff simulation model that incorporates the intra-catchment elements needed to determine runoff from a larger watershed. Tilley et al. (1999) demonstrated the inadequacy of current stream-gauge height-measurement-averaging techniques combined with a rating curve to estimate flow at a site during flash flooding in urban areas. They recommended that the monitored gauge height be used for each subarea for each time increment in order to calculate the volume of flow during a flash flood. Steiner et al. (1999) demonstrated the necessity for having good quality rain gauge data if it will be used to adjust for biases in radar rainfall estimates of precipitation. They concluded that the differences resulting from radar data processing scenarios were small compared to the effects of rainfall data adjustment based on rain gauge information. Maheepala and Perera (1999) described the quality assurance checks program used during the collection of urban drainage hydrologic information for a flood-prediction model for Victoria, Australia. They discussed not on the quality of the data but also the occupational safety and health aspects of collecting it. Gutierrez (1999) reported on the development of regional regression equations for predicting flows at ungaged urban catchments in Mexico.

Riotte and Chabaux (1999) found that the ratio of U-234/U-238 could be used to investigate hydrological processes such as flooding events. Weiler et al. (1999) used natural tracers/isotopes with mass balance calculations to determine the fraction of surface flow and subsurface flow in the receiving water prior to a rain event. The isotopes were also used to demonstrate the importance of infiltration water to the quantity of subsurface runoff due to preferential flow. McDonnell et al. (1999) combined tracer studies (using ^{18}O) with measures of rainfall and runoff in four nested catchments on South Island, New Zealand. The results showed that water contributions from various source areas in a catchment was a complex function of the mixing of these contributions and of the contact time in the groundwater and drainage system. Mehlhorn and Liebundut (1999) determined that the modeling approaches for tracer hydrology and rainfall-runoff modeling were mathematically equivalent and therefore, tracer time parameters could be used to calibrate baseflow runoff models. Coupling the water age and turnover time of the mobile groundwater led to a more accurate determination of the baseflow in the stream.

Post et al. (1999) used hand-held radiometers to evaluate the ground cover of semiarid rangelands and to correlate the data collected with the hydrologic characteristics of the area. The results showed that vegetative cover and percent runoff were highly correlated with spectral reflectance, while soil-rock cover and eroded sediment were poorly correlated with the reflectance.

Testing for chemical pollution and pollution tracers. Maldonado et al. (1999) evaluated the use of trialkylamines and coprostanol as chemical tracers of pollution in the western Mediterranean and the northwestern Black Sea from urban areas. Trialkylamines were found to be the better marker of urban pollution in the water because they had higher concentrations in the water and were not as likely to associate with the particulate phases. Sidle and Lee (1999) used the deuterium isotope to determine the origin of the stormwater runoff from an urban watershed. Deuterium isotope concentrations were significantly different in the vadose and saturated zones between an area affected by a storm sewer leak and an area where a stream contributes to the groundwater. The measurements were useful in modeling leaks and seepages and in improving mass balances in urban watersheds.

Soerens et al. (1999) reported on the development of a sampling scheme to find the minimum required sampling interval during a storm that would be necessary to obtain realistic pollutant loadings for TMDLs. They found that the optimum sampling interval was dependent on the parameter measured and the stream order. Persson et al. (1999) developed and demonstrated a passive in-situ sampler for metals in stormwater runoff. The results indicated that the metals concentration in the passive sampler corresponded to the bioavailable fraction of the metals in the runoff. They also found that in-situ deployment of the passive sampler with direct analysis of the water by laser ablation-ICP/MS provided better accuracy than traditional bottle sampling, either a grab or a composite sample.

Microbiological testing. Myrmel et al. (1999) presented their work on using adsorptive filtration and PCR to detect small round-structured viruses in water and wastewater. The method detected virus concentrations of 0.5 – 5 virus particles per milliliter in a 500-mL sample. Abbaszadegan et al. (1999) compared PCR to cell culture testing for the detection of viruses in groundwater. They found that, with the improved sample-processing technique and large-volume amplification protocol, the PCR test was a rapid and effective tool for screening water for enteroviruses, hepatitis A virus, and rotavirus. Betts (1999) reported on the evaluation of “DNA chip” technology for the rapid, sensitive and inexpensive testing of water for bacteria, parasites and viruses. Zisette et al. (1999) used a genetic fingerprinting technique to assist in identifying source of microbial contamination to Drayton Harbor Watershed, Washington. The results from the bacterial tests were then to be used to determine which sources (municipal sewage discharge, failing septic systems, animal management practices, seafood processor discharges, and people who live aboard houseboats at the marina) were causing the shutdown of the oyster and shellfish harvest areas. Clancy and Hansen (1999) discussed the lack of use of protozoan monitoring data in public health decision-making. They found in their survey that the primary reason cited by water companies was unreliable data. However, the protozoan data has been used successfully in conjunction with other water quality results to assess treatment efficiency and support investment planning.

Matlock et al. (1999) used the Matlock Periphytometer to measure nutrient limitations and trophic status in situ in the Bosque River Watershed in Texas. The data was used to develop a lotic ecosystem trophic status index (LETSI), and through the use of LETSI, differences in nutrient limitations in tested streams were detected, including two streams which were co-limited by nitrogen and phosphorus. Toetz et al. (1999) related annual phosphorus loadings from eight subbasins in the Illinois River impacted by NPS runoff to the alkaline phosphatase activity (APA) in the water. The correlation between APA and soluble reactive phosphorus and between APA and the annual predicted phosphorus loading by the SIMPLE model allowed the researchers to demonstrate which of the eight subbasins did not require pollution abatement and were not in jeopardy of becoming eutrophied.

Toxicological testing. Doherty et al. (1999) compared *Ceriodaphnia dubia* and the Microtox® inhibition tests with *Vibrio fischeri* on industrial and municipal wastewaters. For samples that were not toxic, the Microtox® method correlated well with the results with the *C. dubia* results. However, for samples that were toxic to *C. dubia* after 24 hours, the Microtox® detected toxicity in only two. For five other samples that the Microtox® found to the toxic, the *C. dubia* required a minimum of 48 hours of exposure before toxicity could be detected. Kosmala et al. (1999) used *C. dubia* in laboratory toxicity tests in combined with field analysis of the *Hydropsychid* life cycle to assess the impact of both the wastewater treatment plant effluent and the stormwater overflow on the receiving water. They found that the results seen in the laboratory toxicity tests and in the in-situ biological measurements were due to nutrient and micropollutant loadings. Marsalek et al. (1999) used several different toxicity tests to assess the various types of toxicity in typical urban runoff and in runoff from a multi-lane highway. The tests included traditional toxicity analysis using *Daphnia magna*, the Microtox® toxicity test, sub-mitochondrial particles and the SOS Chromotest for genotoxicity. Tucker and Burton (1999) compared in-situ versus laboratory conditions for toxicity testing of nonpoint-source runoff. They found that NPS runoff from urban areas was more toxic to the organisms in the laboratory while the agricultural runoff was more toxic to the organisms exposed in situ. The differences seen between the two types of toxicity tests demonstrated the importance of in-situ assays in assessing the effects of NPS runoff. Fry (1999) measured the concentration of stable C and N isotopes in the clam *Potamocorbula amurensis* in San Francisco Bay. He determined that the carbon isotope concentrations in the clam correlated to the amount of riverine, freshwater, input into the Bay while the nitrogen isotope concentrations could be correlated to the watershed nutrient loadings due to human activity.

Risk Assessment

The Office of Water at U. S. Environmental Protection Agency (1999) published *CSO: Guidance for Monitoring and Modeling* as a reference for persons and institutions involved in evaluating the effects of CSO on all users of an impacted receiving water. Bickford et al. (1999) reported on the methodology developed and implemented by Sydney Water to assess the risk to humans and aquatic organisms in creeks, rivers, estuaries and ocean waters from WWF. The model used in this study was designed to predict concentrations of various chemicals in WWFs and compare the values to toxicity reference values. Brent and Herricks (1999) proposed a methodology for predicting and quantifying the toxic response of aquatic systems to brief exposures to pollutants such as the contaminants contained in stormwater runoff. The method contains an event-focused toxicity method, a test metric (ETU, event toxicity unit) to represent the toxicity of intermittent events, and an event-based index that would described the acute toxicity of this brief exposure. The toxicity metric proposed (PE-LET50 [post-exposure lethal exposure time]) was the exposure duration required to kill 50 % of the population during a pre-specified, post-exposure monitoring period. Colford et al. (1999) proposed three methods of analytically evaluating the impact of storm sewer and combined sewer outflows on public health, especially in areas that may receive through deposition the harmful agents in sewage and combined sewage. In the Puget Sound region of the U.S. Pacific Northwest, Greenberg et al. (1999) developed and evaluated the Urban Stream Baseline Evaluation Method to characterize baseline habitat conditions for salmonids. The methodology, based on assessment of geomorphic suitability, fish distribution and habitat alteration, was recommended for use to prioritize recovery actions. Stewart et al. (1999) collected diatoms (*Bacillariophyta*) and water quality samples from three streams that drain the Great Marsh in the Indiana Dunes National Lakeshore. They found that diatom species diversity could be used as indicators of water quality, which could then be linked to land use in a watershed. Diatom species diversity was most variable in areas with poorer water quality and was directly correlated to the total alkalinity, total hardness and specific conductance of the water in the stream.

Easton et al. (1999a and 1999b) presented the first phase of a project for determining the risk associated with human contact with waters contaminated with sewage-borne pathogens. Determination of the survival rates for these pathogens has been found to be crucial for determining the length of time after a contamination episode that the water was unsafe for human contact such as wading, swimming, etc. Die-off rate studies for total coliforms, *E. coli* (including *E. coli* 0157:H7), *Enterococci*, and *Giardia lamblia* were performed in situ in a stream known to have SSO. The survival rates, when combined with local hydrologic data, would be used to predict fate and transport of these microorganisms. Wakeham (1999) reported on the results of the investigation to determine why an $800 million investment program designed to improve swimming water quality in the northwest coast of England was not effective. They found that the problem of compliance with water quality criteria for human exposure to pathogens was more complex than originally believed and that current data analysis techniques and models by themselves could not completely described the complex environment.

Surface-Water Impacts

David et al. (1999) performed a study to determine the response of stream water dissolved organic carbon (DOC) and organic acidity to increased inputs of ammonium sulfate to a whole catchment. Several mechanisms exist, including evaporative concentration, vapor-liquid phase partitioning, lowered washout volumes of atmospheric deposition water, and dry deposition, which may lead to elevated concentrations of trifluoroacetic acid (TFA) in atmosphere and surface waters above levels expected from usual rainfall washout (Wujcik et al., 1999). Correll et al. (1999a) reported on a study to determine the relationships between precipitation at the seasonal and annual scale and water discharge per surface area for seven contiguous first and second-order tributaries of the Rhode River, a small tidal tributary to the Chesapeake Bay, Maryland.

Mason et al. (1999a) reported that the chemistry of a first-order stream in Amherst, Maine with a catchment area of 103 ha has been strongly altered as a result of road salt application at a rate of approximately 4 t of NaCl per year in the lower 15 % of the catchment. Pesticide compounds, relative to the landuse composition of the basin, were detected in all 50 water samples collected from streams in New Jersey and Long Island, New York, during June 9-18, 1997. Physical and chemical properties as well as application rates of the pesticides studied affect their detection frequencies. Although all pesticide concentrations were within both EPA and State maximum contaminant levels (MCL) and health advisory levels (HAL), these criteria apply only to individual compounds, and more than one compound was detected in 49 of the 50 samples collected (Reiser and O'Brien, 1999). Watershed properties such as peatland area have considerable promise as predictors for estimating total mercury (THg) transport in streams draining forested watersheds in the Great Lakes States (Kolka et al., 1999a and 1999b). Sixteen largely agricultural watersheds in the upper portion of the North Bosque River of central Texas were reported by McFarland and Hauck (1999). The proportion of total P (TP) in runoff represented by soluble reactive P (SRP) also increased as the percent of dairy waste application fields above a sampling site increased.

Approximately 1,100 communities in the United States have combined sewer and storm water systems whose capacity may be exceeded during moderate or heavy rainfall. Outflows may occur that can deposit water with varying concentrations of the components of sewage onto public areas, potentially resulting in a range of adverse health effects (Colford et al., 1999). Seasonal and event variations in stream channel area and the contributions of channel precipitation to stream flow were studied on a 106-ha forested headwater catchment in central Pennsylvania. Variations in stream velocity, flowing stream surface width and widths of near-stream saturated areas were periodically monitored at 61 channel transects over a two-year period (Crayosky et al., 1999). Johnson et al. (1999a) presented information that suggest non-stormwater source, such as on-site sewage systems and illicit discharges, were major contributors to the contamination of the Rouge River in Wayne County, Michigan.

Surface-water effects – temperature. Picksley and Deletic (1999) studied the thermal behavior of storm runoff from paved surfaces at two different urban catchments. The thermal trends were explained by equilibrium of thermal influences, based on the physical interaction of runoff and paved surfaces.

Erosion and channel stability. Ghani et al. (1999) found that the thickness of a sediment deposit on the bottom of a rigid rectangular channel greatly affects its erodibility of the deposits. They developed channel erosion equations that included terms for the deposit's thickness. Keshavarzy and Ball (1999) studied the entrainment of sediment particles in water and found that the number of entrained particles per unit time per unit area was found to be related to the instantaneous shear stress at the bed. These results were used to modify the Shields diagram. Ashley et al. (1999)

investigated the integration of sewer solids' biodegradability into the existing UK waterway protection standards for solids erosion in sewers. This integrated standard would then be used to define the DO criteria in streams and to determine the allowable solids discharge. Rhoads and Cahill (1999) studied the elevated concentrations of chromium, copper, lead, nickel and zinc that were found in sediments near storm sewer outfalls. They noted that copper and zinc concentrations were greater in the bedload compared to the bed material and therefore were more likely to be mobilized during runoff events.

Biological and microbiological impacts. Bailey et al. (1999) investigated the potential toxicity of stormwater runoff from sawmills in British Columbia to juvenile rainbow trout, and found that the toxicity was related to the divalent cation concentration, especially for zinc. They also determined that the zinc toxicity was directly related to the low hardness in the stream, with the range of LC50 of 72 – 272 µg/L associated with hardnesses of 9 – 100 mg/L. Ambrose and Meffert (1999) investigated the fish assemblages in Malibu Lagoon, a small estuary in California, and found that the species diversity and richness were small compared to large estuaries, but were comparable to other small estuaries with less anthropogenic impacts. Hatch and Burton (1999), using field and laboratory bioassays, demonstrated the impact of the urban stormwater runoff on *Hyalella azteca*, *Daphnia magna*, and *Pimephales promelas* survival after 48 hours of exposure. The significant toxicity seen at the outfall site was attributed to the contaminant accumulation in the sediments and the mobilization of the top layers of sediment during storm events. A comparison of highway runoff toxicity with typical urban runoff toxicity was performed by Marsalek et al. (1999). Their study found that approximately 20 % of the samples collected at the edge of a multi-lane divided highway (>100,000 vehicles/day) were severely toxic, while only 1 % of the typical urban runoff was severely toxic. Skinner et al. (1999) showed that stormwater runoff produced significant toxicity in the early life stages of medaka (*Oryzias latipes*) and inland silverside (*Menidia beryllina*). Developmental problems and toxicity were strongly correlated with the total metal content of the runoff and corresponded with exceedances of water quality criteria of Cd, Cu, W, and Zn.

Ecotoxicological experiments were used by Delbec and Muchel (1999) to develop a wet-weather quality potential

(Φ) that can be used to evaluate oxygen depletions during WWF. The quality potential was used to demonstrate the impact of seasonal hydrological conditions on the occurrence of damaging situations in the River Seine. Pess and Bilby (1999) identified Coho salmon (*Oncorhynchus kisutch*) distribution and abundance in Puget Sound rivers and explained the distribution by using both stream-reach and watershed-scale habitat characteristics, including the influence of urban areas on the habitat. Tree swallows were used by Secord et al. (1999) to determine the impact of contamination of a watershed and waterway with PCB. The elevated PCB concentrations in the swallows and in the sediments indicate that PCBs in the sediments can be passed up the aquatic food web of the Hudson River ecosystem to the terrestrial and avian wildlife that depend on the River for food. Mallin et al. (1999) documented the effects of Hurricanes Bertha and Fran on the biological community in the Cape Fear area of North Carolina. The natural hurricane effect of swamp water flooding into river basins was reduced DO levels that resulted in fish kills. However, this damage, such as the length of the low DO levels, was considerably increased by anthropogenic practices, including sewage diversions into the rivers and flooding and discharge from swine waste lagoons sited adjacent to the river. The relationship between benthic chlorophyta (*Ulothrix zonata*) and urban stream water quality was demonstrated by Shigemitsu and Hiratsuka (1999).

Crabill et al. (1999) presented their analysis of the water and sediment in Oak Creek in Arizona, which showed that the sediment fecal coliform counts were on average 2200 times greater than that in the water column. Water quality standards for fecal coliforms were regularly violated during the summer due to the high recreational activity and animal activity in the watershed, as well as the storm surges due to the summer storm season. Lemke and Leff (1999) analyzed the bacterial populations at five sites, including two in disturbed urban streams. The results indicated that anthropogenic disturbance of watershed and stream can alter some bacterial populations (*Acinetobacter calcoaceticus*) but not others (*Burkholderia cepacia, Pseudomonas putida*). Haile et al. (1999) presented the results of an epidemiological cohort study of swimmers in Santa Monica Bay, California where untreated urban runoff from Los Angeles was discharged. Higher risks of upper respiratory and gastrointestinal infections were found for swimmers near storm-drain outfalls, in waters with a low ratio of total to fecal coliforms, and in waters where enteric viruses were detected. Herrmann et al. (1999b) demonstrated through modeling that, for a German city with a combined sewer system, blackwater separation by vacuum toilets and urine separation can reduce nutrient discharges during overflow events by 90 %, especially in the summer when the river water may contain up to 50 % sewage. These reductions in nutrient discharges might improve the river water quality sufficiently to meet swimming water quality criteria during most, if not all, of the year.

Chemical impacts. Stieber et al. (1999) statistically related the pollutant load in urban runoff to interevent dry period and rainfall intensity with the ultimate goal of developing a simple relationship between the rain variables and the pollutant loads. The relationship could be used by planners and engineers to evaluate the effectiveness of pollutant reduction mechanisms. Bamford et al. (1999) investigated the fluxes of PAH at the air-water interface of the Patapsco River and found that the fluxes were highest adjacent to stormwater discharges due to the elevated concentrations of PAH in the stormwater runoff. A major source of the PAH, benzo(ghi)perylene, pyrene and fluoranthene in the rivers in the Paris metropolitan area was found by Ollivon et al. (1999) to be car-park dust due to motor vehicle combustion. During heavy rainfall events, PAH primarily were leached from urban surfaces and transported to the rivers. Zheng and Richardson (1999) related the high concentrations of petroleum hydrocarbons and PAH in Hong Kong marine sediments to the heavily urbanized or industrialized areas surrounding the most heavily polluted sites. They showed that the oil and its products were the major sources of hydrocarbons in sediments. Stormwater runoff from an urban highway in Xi'an, China was shown by Zhao et al. (1999) to contain BOD, COD and suspended solids concentrations at least as strong as typical domestic effluents. However, the biodegradability of the organic compounds in the runoff (BOD:COD = 0.167) was low. Regression equations were developed for BOD and COD and for suspended solids and COD in urban runoff from the highway. Gupta et al. (1999a and 1999b) investigated the sources of pollutants to Talkatora Lake in Jaipur, India. They found, using a mass balance of the lake, that the major cause of pollution to the lake was the first flush of stormwater runoff from the adjacent residential and commercial areas.

Bendoricchio et al. (1999) demonstrated that nutrient concentrations in runoff varied during rain events and that the deterioration of water quality in the Lagoon of Venice, Italy, was related to the diffuse pollution sources in the watershed. As the point sources of pollution were controlled, the relative importance of NPS increased, and effectiveness of the Lagoon restoration would depend on controlling the diffuse sources of the nutrients. A water quality index (WQI) was developed by Peters and Kendell (1999) for streams in the Atlanta, Georgia region, and the sampling data showed that the WQI for nutrients was best for the low-density residential areas and worst for the industrial area. Yung et al. (1999) investigated the physico-chemical and biological changes in Victoria Harbor, Hong Kong and found that water temperature, total and ortho-phosphorus, and fecal bacteria were increasing, while pH, total nitrogen, TKN, BOD and chlorophyll a were decreasing. However, sampling sites not in the main Harbor did not reflect these trends, although all sites reflected the fact that Victoria Harbor and its vicinity were polluted by sewage effluent, stormwater runoff, marine traffic, construction, and industrial activities.

Crosbie and Chow-Fraser (1999) investigated the impact of land use on the water and sediment quality in 22 marshes in Ontario, Canada. The concentration of inorganic solids, sediment phosphorus, metolachlor, and ionic strength were positively correlated with the percentage of agricultural land in the watershed, while the concentrations of PAH were positively correlated with the percentage of urban land. Heal (1999) demonstrated the accumulation of copper, nickel and lead in the sediments of a wetland and two detention ponds receiving urban storm runoff in Scotland. Sediment metals concentrations, however, were highly variable within each structure, possibly indicating short-circuiting through the ponds and wetland. Platinum, palladium and rhodium were found in road sediments by Rauch et al. (1999a) with their concentrations increasing since 1984. The increase in bioaccumulation of rhodium in *Aseltus aquaticus* in urban rivers was linked to the increased sediment concentrations of these automobile-derived metals. Shafer et al. (1999) investigated the partitioning of trace metal levels (Al, Cd, Cu, Pb, and Zn) in Wisconsin rivers and found that the concentrations in the rivers were comparable to recent data collected in the Great Lakes and other river systems where ‘modern’ clean methods were used for sampling and analysis. They also found that the variation in the partitioning coefficients of each metal between sampling locations could be explained by the amount of anthropogenic disturbance in the watershed and by the concentration of dissolved organic carbon (DOC) in the water.

Environmental effects of CSO and SSO. CSO and SSO can have damaging impacts on receiving waters. Sanudo-

Wilhelmy and Gill (1999) compared current pollutant concentrations in the Hudson River Estuary, New York with concentrations measured in the 1970's. The concentrations of Cu, Cd, Ni, and Zn have declined, while concentrations of dissolved nutrients (PO_4) have remained relatively constant during the same period of time, suggesting that wastewater treatment plant improvements in the New York/New Jersey Metropolitan area have not been as effective at reducing nutrient levels within the estuary. Rather than inputs from point sources, the release of Pb and Hg from watershed soils, and Ni and Cu from estuarine sediments, may represent the primary contemporary sources of these metals to the estuary.

David and Matos (1999) discussed the difficulties of modeling and regulating the effects of CSO and stormwater discharges on the water quality in Portugal's rivers. Emphemeral river flows, rainfall patterns that differ from north to south, the effects of pollutant transport dynamics in sewers and pavements, and bed river resuspension during storms all influence river water quality. To understand the effect of CSO on the river Seine (France), a characterization of effluent in terms of organic matter and bacterial biomass was carried out during several sampling campaigns performed in a combined sewer located in Parisian suburbs under wet- and dry-weather conditions. The only two small differences in relative composition that could be observed between dry and wet weather were slightly lower content of organic carbon in suspended solids and a lower biodegradability of this material during rain events (Servais et al. 1999). Vollertsen et al. (1999b) characterized the biodegradability of combined-sewer organic matter based on settling velocity. Fast settling organic matter, which represents the largest fraction of the organic material, was found to be rather slowly biodegradable compared to the slow settling organic fraction. The biodegradability of sewer sediments was argued to be taken into account for detailed characterization when dealing with CSO impacts. Vollertsen and Hvitved-Jacobsen (1999) studied the stoichiometric and kinetic model parameters for predicting microbial transformations of suspended solids in combined sewer systems.

CSO/SSO impacts. Mason et al. (1999b) showed that the Chesapeake Bay was an efficient trap for mercury. However, in the estuary, methylation of the mercury occurred, the Bay became a source of methylmercury, and on a watershed scale, only about 5 % of the total atmospheric deposition of mercury was exported to the ocean. Venkatesan et al. (1999) investigated the potential for using sediment cores to determine the history of chlorinated pesticide and PCB application in a watershed. They found that the sediment cores accurately reflected the length of use of these chemicals in the watershed, and that the surface sediment layer, after mixing and resuspension was accounted for, reflected the reduction in use that had occurred during the last few years.

Bellefleur et al. (1999) summarized the data available on the water quality of combined sewer flow in Roeschwoog. The data that these flows impacted the physical and chemical water quality of the Sauer; however, an impact of CSO on the biological integrity was not easily seen. Classification of the rainfall into eleven types of events allowed the investigators to estimate the total loads from polluted overflows during a typical year. Herrmann et al. (1999a) found that the discharge of urea, which hydrolyzes to ammonia with a corresponding increase in pH, could cause fish toxicity after a CSO event. The concentration of ammonia plus urea in the combined sewer discharge was found to be a more relevant measure of the likelihood of a fish kill after an overflow event than the concentration of ammonia alone. Saul et al. (1999) investigated the production of undesirable solids in combined sewer flows as it related to social, economic and ethnic factors. The goals of the research were first to determine the differences in the characteristics of the solids in the sewers that were ultimately discharged to the receiving water and then to use the solids' characteristics to predict the efficiency of CSO treatment devices, especially CSO chambers. St. Michelbach and Brombach (1999) showed that the nutrient content, especially of dissolved phosphorus, from CSO and existing wastewater treatment plants (WWTP) was endangering the health of Lake Constance. They proposed a simple methodology to estimate the nutrient loads from CSO to the Lake, the results of which can be used to determine the cost-effectiveness of CSO improvement versus WWTP improvement.

Habitat Management and Restoration

Bragg and Kershner (1999) investigated another aspect of biological impacts – the impact on the habitats of aquatic life – and they found that coarse woody debris in riparian zones can be used successfully to maintain the integrity of these ecosystems. Larson (1999) evaluated the effectiveness in urban areas of these habitat restoration activities using large woody debris and found that in urban areas, the success of restoration may be hindered by the high sediment loads and increased flow associated with urbanization. Markowitz et al. (1999) documented the CSO Long Term Control Plan implemented by the City of Akron, Ohio which focused on habitat preservation and aquatic life use of the receiving waters. The plan included these non-traditional alternatives: riparian setbacks in undeveloped areas, stream restoration, linear parks or greenways and artificial riffles for stream aeration, and were found to cost less than five percent of the typical cost of controlling CSO flows. A methodology to investigate the chronic and cumulative degradation of the river Orne due to CSO and urban runoff was presented by Zobrist et al. (1999), with the results being used to evaluate management activities. O'Meara et al. (1999) reported on the restoration of Newburgh Lake on the Middle Rouge River in Wayne County, Michigan. The $11.8-million restoration consisted of removing PCB-contaminated sediment and fish, construction of new fish habitat, and restocking of beneficial fish and aquatic plants. Xu et al. (1999) reported on the improvement plan being used for a river passing through the downtown area of a city in Western Japan and the problems that were inherent with developing a compromise strategy between flood control and mitigation and the desire to have an attractive waterway through the city. The final improvement plan recommended construction of a new flood drain tunnel and a new underground flood control reservoir.

Cianfrani et al. (1999) used a GIS system to document the results of a comprehensive inventory of the natural resources of the Fairmount Park (Philadelphia, Pennsylvania) stream system, including vegetation communities, fish, aquatic and terrestrial insects, birds, mollusks, amphibians, reptiles, and streams. The stream assessment also included the characterization of stream reaches by in-stream habitat, geomorphology and riparian zone. This GIS inventory then was used in planning the restoration of sites in the Fairmount Park system. Derry et al. (1999) reported on the habitat management strategies implemented by the City of Olympia, Washington, to control the degradation of aquatic habitats by urban stormwater runoff. These management strategies provided a basis for resolving the conflict between growth and the protection of aquatic resources. Ishikawa et al. (1999) reported on the efforts to restore the hydrological cycle in the Izumi River Basin in Yokohama, Japan while Saeki et al. (1999) have documented the efforts of the Tokyo Metropolitan Government and its Basin Committee to restore the natural water cycle in the Kanda River. Kennen (1999) investigated the relationship between selected basin and water-quality characteristics in New Jersey streams and the impact on the macroinvertebrate community and its habitat. He found that urban areas had the greatest probability of having impacted stream areas, with the amount of urban land and the total flow of treated sewage effluent being the strongest explanatory variables for the impact. He also found that levels of impairment were significantly different between the Atlantic Coastal Rivers drainage area and the Lower Delaware River drainage area.

Jarrett et al. (1999) analyzed the data collected from 1991 through 1998 as part of the stream-monitoring program implemented in Louisville and Jefferson County, Kentucky. They found that recreational contact standards for fecal coliforms were exceeded during WWF and that much of the pollutant loadings of suspended solids and BOD were also contributed by WWFs. However, they found that the nutrient loadings were more varied with some impact seen from wastewater treatment plants. The concentrations of phosphate, total phosphorus, and total volatile solids in the streams were reduced as more of the watershed was sewered. Reduction of eutrophication through the treatment of stormwater runoff with storage facilities and wetlands for Lake Biwa was proposed by Hidaka et al. (1999). It was estimated that this storage and treatment could reduce the COD load to the lake by nearly 70 %. However, wetlands could be overloaded and the water quality of its effluent degraded, as demonstrated by Noguchi et al. (1999) in their study of the regulation pond/wetland in Isahaya Bay, Japan. In order to prevent eutrophication of the regulatory pond it was found to be necessary to control nonpoint sources of nutrients in runoff.

Groundwater Impact

NPS contamination of surface and groundwater resources with nitrate-N (NO_3-N) has been linked to agriculture across the midwestern United States (Cambardella et al., 1999). Moorman et al. (1999) reported that herbicide, mainly atrazine and metribuzin, transport in subsurface drainage and shallow groundwater can result in unacceptable levels of contamination in surface waters. An investigation of the Walnut Creek watershed, California was performed to characterize the geology, groundwater flow, and water quality in geological units impacted by agriculture (Eidem et al., 1999). The infiltration of dissolved herbicides and metabolites from a tributary stream can occur where the stream crosses a floodplain overlying an alluvial aquifer causing the contamination of shallow alluvial aquifers at rates that exceed in-field leaching by up to three orders of magnitude (Burkart et al., 1999).

Hatfield et al. (1999a and 1999b) examined a multi-disciplinary study on the effect of farming practices on subsurface drainage, surface runoff, stream discharge, groundwater, volatilization, and soil processes that influence water quality. Groundwater was vulnerable to contamination in karst areas where highway stormwater runoff may flow directly into karst aquifers with little or no natural attenuation and transport highway-derived contaminants rapidly from sinkholes to locations in the aquifer.

Control of stormwater in sinkhole areas of Springfield, Missouri has involved the utilization of several standard approaches: concrete-lined channels draining into sinkholes; installation of drainage pipes into the sinkhole "eyes" (swallow holes); filling of sinkholes; elaborate drains or pumps to remove stormwater from one sinkhole and discharging into another drainage basin or sinkhole; and enlargement of swallow holes by excavation to increase drainage capacity. Three sites were analyzed to examine the effectiveness of contrasting design approaches to stormwater management. These sites differ in vegetation, on-site/off-site considerations, and types of development proposed (Barner, 1999). Since little was known about the influence of micoorganisms which develop in urban stormwater infiltration basins on the transfer of heavy metals. Hebrard and Delolme (1999) examined the transfer of zinc solutions (2-20 ppm) at different pH (4-7) by columns of sterile sand or sand colonized with Pseudomonas putida. By the analysis of the observed time series of streamflow from catchments, the main components of the underlying groundwater balance, namely, discharge, evapotranspiration loss, storage and recharge, can be identified and quantified. This holistic estimation method was demonstrated for the Harris River catchment in southwest Western Australia (Wittenberg and Sivapalan, 1999).

Planned groundwater recharge. Dillon et al. (1999) reported on the use of storage aquifers under urban areas to enhance groundwater recharge and to decrease the volume of surface runoff and combined sewer effluent reaching the receiving waters. Similarly, Lin et al. (1999) discussed the use of reclaimed wastewater plus stormwater to recharge the groundwater in the Caprock Aquifer in Oahu, Hawaii. Munevar and Marino (1999) developed a model for evaluating the artificial recharge potential on alluvial fans in the Salinas Valley in California. They found that average recharge/infiltration rates ranged between 0.84 and 1.54 cm/hr and that recharge efficiency ranged from 51 to 79 %. Their model results demonstrated that planned recharge and streamflow augmentation could significantly reduce the groundwater overdraft and seawater intrusion in the area. Shentsis et al. (1999) reported on the transmission losses and groundwater recharge, including transmission losses from the vadose zone, from rainfall-runoff events in a wadi in Israel. They found that, during large events, evaporation was substantially smaller than the losses. However, in general, the annual recharge was very small, while losses were on the same order of magnitude as the stream flow. Wittenburg and Sivapalan (1999) used streamflow recession analysis and baseflow separation to quantify the components of the groundwater, i.e., discharge, evaporation losses, storage and recharge. Groundwater evaporation through water uptake by trees biased the recession curve. Data analysis of the data, stratified by time of the year, allowed the evaporation loss to be quantified as a function of time of the year and the used groundwater storage.

Generally, igneous and metamorphic rocks have been considered to be barriers to groundwater flow, while carbonates were assumed to allow flow through their fractures. Thyne et al. (1999) found, however, recharge occurring in the Indian Wells Valley through flow in a fractured bedrock that was originally thought to be impermeable. Their results demonstrated that using surface topography along with a knowledge of the location of the bedrock to estimate groundwater flow quantity and direction may not be suitable.

Microbiological impacts. Barrett et al. (1999) suggested the use of chemical and biological markers for identification of urban groundwater recharge sources. Their paper documented only the sewage ‘fingerprint,’ a combination of stable nitrogen isotopes and microorganisms. Trihalomethanes had been proposed as a marker for leaks in the drinking water mains, but they were not found in sufficient quantity in the drinking water itself to be an effective measure of groundwater contamination. Markers were not presented for precipitation.

Soil application was proposed as a means of disposal of propylene glycol-based aircraft deicing fluids (ADF). ADF biodegradation was investigated by Bausmith and Neufeld (1999) and the results showed that biodegradation of solutions of less than 20 % by weight ADF could be degraded in the soil profile prior to reaching the groundwater. Degradation of the groundwater by human and animal excrement was documented by Buckles et al. (1999) for an area in Ecuador where the groundwater table was rising. The degradation of the groundwater in combination with the rising water table produced swamp-like conditions where the water and land were not suitable even for subsistence farming.

Chemical impacts. Barraud et al. (1999a) reported on the quality of the groundwater below two infiltration sites in urban areas of France. Kayabali et al. (1999) investigated the chemical contamination of the groundwater in alluvial aquifers adjacent to Ankara Creek since it was believed that Ankara Creek pollution was contaminating the local groundwater. However, it was determined, using analysis of basic ions, organics and metals, that Ankara Creek was not responsible for groundwater contamination, partly because a blanket of fine sediment in the bottom of the creek was expected to adsorb pollutants and to reduce infiltration rates. Lerner et al. (1999) combined a water balance with multiple solute balances to model the flow of water and chemicals into the groundwater under Nottingham, UK. They found that sewers contributed only about 13 % of the total nitrogen loading, while leaking drinking water mains was about 36 % of the total. The remaining 50 % of the nitrogen loading came from parks, gardens, landfills and industrial spillages. Reddy (1999) reviewed the available data from public water suppliers in Wyoming which use groundwater. Nitrate and pesticides were two of the most frequently detected contaminants in groundwater and two of the most frequently detected pesticides were aldicarb and atrazine. Groundwater contamination was found to be a problem especially in areas that were heavily agricultural. Stephenson et al. (1999) investigated the impact of highway storm water runoff flowing through a karst area and found that little to no attenuation of the runoff pollutants occurred. For most of the contaminants analyzed, the peak loadings arrived at the groundwater table and at the spring it recharges approximately one hour after they were found in the sinkhole that received the highway drainage. Nowicki et al. (1999) found that denitrification of groundwater was not significant in a well-oxygenated vadose zone and aquifer. Denitrification was found to occur to a greater extent in the estuary which receives the groundwater. Mengis et al. (1999) used nitrate-to-chloride ion ratios, concentrations of 15-Nitrogen and 18-Oxygen and an in-situ nitrate/15-N tracer experiment to investigate whether nitrate was being attenuated in the vadose zone and/or the aquifer below a riparian zone. Their results confirmed that denitrification rates could be measured in situ using this procedure. They also confirmed that this methodology could distinguish between water being recharged from the riparian zone versus that being recharged from irrigation of the nearby agricultural fields.

DECISION-SUPPORT SYSTEMS

Modeling and Model Applications

Nnadi et al. (1999) compared the ability of various design storm distributions to simulate the actual rainfall pattern to the runoff rates used in the design of stormwater management devices in the State of Florida using continuous simulation. According to Murphy and Lokey (1999) a model was developed to assess urban BMP efficiency on the total pollutant load using a simple spreadsheet and Monte-Carlo style simulator. The model suggests that many BMP used to comply with the National Pollutant Discharge Elimination System (NPDES) requirements appear to have little impact on the annual load. It might be argued that many BMP need to be evaluated at the source, not the receiving stream.

The Object Watershed Link Simulation (OWLS) model was developed and used to simulate the hydrological processes within the BBWM. The OWLS model was a three-dimensional, vector-based, visualized, physically-based, distributed watershed hydrologic model. Simulation results provided a close examination of hydrologic processes of flow separations and Variable Source Areas (Chen and Beschta, 1999). Bent et al. (1999) evaluated the runoff and erosion response of two perennial grass species on simulated waste burial covers at Idaho National Engineering and Environmental Laboratory.

A multilayer control structure consisting of an adaptation, an optimization, and a direct control layer, was proposed for the solution of this complex problem (Marinaki et al., 1999). The Monte-Carlo simulation approach was demonstrated in an integrated setting involving models for rainfall characteristics, CSO loads and impacts on the surface water DO. CSO loads were modelled using event lumped non-linear regression models with rainfall as input and with overflow volume, duration and relevant event mean concentrations as output; oxygen depletion in the surface water was described using a dynamic model including oxidation of dissolved COD and nitrification. The parameters of all the models were estimated from observed data on rainfall, CSO load and surface water impacts (Grum and Aalderink, 1999). A two-phase decision-making software, DELTANOE, was used for the choice of BMP in urban stormwater drainage (Barraud et al., 1999b). Two phases: an elimination phase which permits the user to exclude solutions which were identified as unworkable according to site considerations and a decision phase which allows the decision makers to compare and at least to choose a scenario built up with feasible solutions.

Constructed wetlands used for stormwater treatment accumulate metals primarily in their sediment, which has the potential to produce toxic effects in benthic or aquatic organisms. A system dynamics model was developed to represent these processes and the major influences affecting pore water metal activity in a treatment wetland receiving stormwater influent. Simulation results demonstrate that chemical processes of acid volatile sulfide (AVS) and organic carbon in binding metal in reduced sediments were the greatest influences in controlling metal bioavailability (Wood and Shelley,1999). The wetland model utilizes a hydrology model coupled to a hydraulic stream-routing model. A depth-averaged laminar flow model was used to simulate the horizontal movement of stormwater both through and over the wetland sediments, a 400-ha first-order headwater swamp located within the Teeswater River watershed in southern Ontario, Canada. An analysis revealed that the simulated wetland streamflows were sensitive to the antecedent saturation of the wetland sediments, the storage and flow transport characteristics of the wetland sediments, and the conveyance capabilities of the wetland channel system (McKillop et al., 1999). Welker et al. (1999) investigated possible changes to quantity and composition of sewage in the combined sewer system and the WWTP caused by new stormwater management strategies (mainly by disconnecting areas from the sewer system). Various scenarios were developed and the consequences on the water systems were calculated by using the simulation model KOSMO, in a fictional catchment.

According to Strecker et al. (1999b), the EPA cooperative research program with the American Society of Civil Engineers (ASCE) developed a more useful set of data on the performance and effectiveness of individual BMP and to assess the relationship between measures of efficiency and BMP design. BMP monitoring data should not only be useful for a particular site, but also be useful for comparing studies of similar and different types of BMP in other locations. It suggested some of the ways that data should be collected to make it more useful for assessing factors (such as settling characteristics of inflow solids and physical features of the BMP) that might have led to the performance levels achieved. It recommended efficiency calculation methods and appropriate terminology to be used in evaluating BMP assessment studies. In addition, Clary et al. (1999) stated that the National Stormwater BMP Database included test site location characteristics, sponsoring and testing agencies, watershed characteristics, BMP design and cost data, monitoring locations and instrumentation, monitoring costs, precipitation data, flow data, and water quality data. The data retrieval, or search engine, portion of the software enabled users to retrieve BMP data sets based on a variety of search criteria such as geographic location, watershed size, BMP type, and water quality parameters.

Traver (1999) examined the calibration and performance of a hydrologic model in recreating recorded storm events from both the stormwater wetlands and the wetlands stream, and the nutrient removal effectiveness of the stormwater wetland basin. The design of stormwater management systems has become common practice in the last twenty years. The micro- and macro-management of stormwater design was examined from a design engineer's viewpoint based upon the traditional establishment of design values and not just meeting regulatory edicts (Olenik, 1999). The Hydrologic Simulation Program Fortran (HSPF) has been calibrated for a sub-watershed of the Upper Roanoke River system. The model would provide inputs needed by other components of the study in describing environmental impacts of urbanization (Lohani et al., 1999). The software discussed provides a decision support system for drainage engineers involved in the design of stormwater management facilities. The program provides suggested design parameter values that user can modify, test and accept. A special feature allows the output file from one design session to be used as input to automatically test the design for a different storm, test a change in catchment or design parameters or simply to complete a design in two or more sessions (Smith, 1999).

The local Water Authorities of the Basque Country (Spain) have adopted an integrated model for the design of the sewer system of this community. The model was developed specifically for the study of coastal sewerage under dominant wet weather conditions. It includes: (1) Establishment of the site specific statutory requirements and environmental objectives, (2) Design of sewer system components with specific reference to influences on marine water quality, and (3) Development of monitoring programs (Alvarez et al., 1999).

According to Moustafa (1999a), long-term data collected at Boney Marsh, Florida and the EPA wetland database were analyzed to develop a simple tool that can be used to predict and optimize phosphorus retention in wetland treatment systems. Wetland properties such as water loading rate, water depth, P-loading rate, and water retention time were examined for their influence on phosphorus retention. The relationship between wetland properties and phosphorus removal efficiency was reduced to a simple quantitative diagram (The Phosphorus Removal Efficiency Diagram) a simple management tool that predicted expected treatment range using controllable hydrologic conditions.

The responses of ADAPT, a daily water-table management simulation model, to variations in the principal input parameters which define hydrologic response units on a watershed was evaluated (Gowda et al., 1999a). Simulated agricultural runoff amended with sediment, nitrogen, and phosphorus, was passed through an experimental sedimentation basin. A series of six sequential runoff events was run through the basin for each of two treatments. The treatments consisted of one-day and three-day detention times, created using a perforated riser outlet structure (Edwards et al., 1999b). Most hydrologic/water quality (H/WQ) models that use rainfall as input assume spatial homogeneity of rainfall. Under this assumption this study assesses the variability induced in calibrated model parameters solely due to rainfall spatial variability. A large uncertainty in estimated model parameters can be expected if detailed variations in the input rainfall were not taken into account (Chaubey et al., 1999).

The UP (Upscaled Physically-based) hydrological modeling system to the Arkansas-Red River basin, United States was designed for macroscale simulations of land surface processes, and aims for a physical basis and, avoids the use of discharge records in the direct calibration of parameters. This was achieved in a two stage process: in the first stage parameterizations were derived from detailed modeling of selected representative small catchments and then used in a second stage in which a simple distributed model was used to simulate the dynamic behavior of the whole basin. Outputs from the model were discussed, and include river discharge at gauging stations and space-time fields of evaporation and soil moisture (Kilsby et al., 1999). The UP modeling system has been applied to the 570,000 km^2 Arkansas-Red River Basin (ARRB) as part of the UK NERC Terrestrial Initiative in Global Environmental Research (TIGER). The parameters of the ARRB model were physically-based, being derived either from fine-scale, sub-grid, data on the topography and physical properties of the soils, aquifers and vegetation of the basin, or from the results of fine-scale physically-based simulations. The ARRB model, as described here was a first attempt at large-scale physically-based hydrological modeling of the type outlined in the 'blueprint' for the UP system, and gives a clear, positive, indication of the nature and quality of what was currently practical with the approach (Ewen et al., 1999).

Distributed models were more and more used in regional hydrology. One of the main reasons was their essential compatibility with raster data in Geographical Information Systems. Zech and Escarmelle (1999) investigated the possibility of using other kinds of databases designed more specifically for cartography. Cassar and Verworn (1999) described the upgrading of the existing hydrodynamic rainfall runoff model HYSTEM/EXTRAN and the decision finding model INTL for real time performance, their implementation on a network of UNIX stations and the experiences from running them within an urban drainage real time control project. The main focus was not on what the models do but how they were put into action and made to run smoothly embedded in all the processes necessary in operational real time control.

A physically-based model was used to simulate runoff in agricultural watersheds with tile drainage systems. The TOPMODEL, which was based on the detailed topographical information provided by a digital elevation model (DEM), was modified for this simulation study. The simulated hydrologic response was designed to produce several components of the outflow hydrograph which were associated with the various possible flow generation scenarios (Kim et al., 1999).

A procedure was introduced for applying the statistical approach to water-table management models, e.g., DRAINMOD, a H/WQ model used to simulate lateral and deep seepage through the soil profile. In the evaluation procedure, probability distribution functions were developed for the most sensitive input parameters, output probability distribution functions were developed using Monte-Carlo simulation, and the output probability distribution functions were used to assess the model. DRAINMOD performed successfully in the evaluative procedure in predicting the runoff, subsurface drainage volume, and the water-table depth fluctuations, which were expected to be most susceptible to input uncertainty (Sabbagh and Fox, 1999).

Donnelly-Makowecki, and Moore (1999) examined whether the quasi-distributed response function used in TOPMODEL provides superior performance for event simulation in small, temperate forested catchments, compared to lumped reservoir representations of runoff routing similar to those employed in many catchment hydrology models. The alternatives were a two-reservoir black-box model and a three-reservoir model structured to represent our perceptual model of runoff processes based on held observations. A second objective was to test the statistical significance of differences in model performance using a new approach that combines the Jackknife with analysis of variance (ANOVA).

Vertessy and Elsenbeer (1999) described a process-based storm-flow generation model, Topog SBM consisting of a simple bucket model for soil water accounting, a one-dimensional kinematic wave overland flow scheme, and a contour-based element network for routing surface and subsurface flows. Aside from topographic data and rainfall the model has only six input parameters: soil depth, saturated hydraulic conductivity at the soil surface, the rate of decay of saturated hydraulic conductivity at the soil surface with depth, the Manning surface roughness parameter, the maximum (saturated) soil water content, and the minimum (residual) soil water content. The model was applied to La Cuenca, a very small rainforest catchment in western Amazonia that has been well characterized in several hydrometric and hydrochemical investigations.

The Auckland Regional Council (ARC), New Zealand published a manual for design of stormwater quality improvement devices (TP10). Within that manual a modified Rational Method was used for flood estimation. An improved method was developed for estimation of storm runoff to represent the effects of different approaches to land development, including the use of different types of land cover and drainage systems, which could significantly modify the volume, timing and peak rat of runoff (Levy and Papps, 1999). The ARC developed a manual "Low Impact Design for Stormwater Management" (Shaver, 1999a). Schueler et al. (1999) described a series of 22 land development principles developed by a consortium of American planning, road, banking, engineering, development and public safety organisations. The environmental impact assessment database being developed for Project Storm consists of a ranking system to provide comparative data for aquatic resources in terms of existing natural environmental values and existing effects (Stevens et al., 1999). Modelers were often faced with data gaps and other problems which may not even come to light until well into the modeling process. Greer (1999) addressed these issues in the context of a case study of a watershed management project conducted in Silver Lake Watershed in central

Delaware. A suite of hydrologic, sewer system and riverine water quality models have been used to address technical questions that have been asked in Rouge River Watershed (Michigan) planning (Kluitenberg et al., 1999).

CSO modeling and analysis. Modeling and analysis of combined sewer systems received considerable attention. Milina et al. (1999a) described the development of an integrated model and its application to the Hovringen wastewater system in Trondheim, Norway. The model integrates sewage production, transport and treatment simulation, the interface with existing databases and the simulation of processes that were controlled in real time, and has been used to design the treatment process as well as static and dynamic measures in both the catchment and the sewer system. Krebs et al., (1999b) use measurements and numerical simulations to show that the first flush effect may cause a significant impact on the receiving water when CSO occurs, or on a wastewater treatment plant when the sewer network was flat and catchment area was large.

Furumai et al. (1999) applied a distributed model to study the reduction of CSO pollution for a combined sewer system in Japan, which contains a storage pipe with 3 weirs for inundation control. Results indicate that the model can be applied for evaluating effectiveness of modified operation or new installation in the sewer system for suspended sediment load reductions, once initial conditions on surface deposits and sediments were properly determined. Jack et al. (1999) described a study which utilized detailed simulation models of the sewerage and treatment plant performance for the City of Perth in Scotland in order to investigate the potential problems caused by introducing system storage to control both flooding and polluting spills.

Miles et al. (1999) presented a method of analyzing flow and rainfall monitoring data that has successfully documented rainfall dependent infiltration and inflow (RDI/I) reduction in Charlotte, North Carolina and Greenville, South Carolina. The method relies on scientific principles including good data quality control practices and the use of control areas to establish changes in RDI/I between monitoring periods because of environmental factors. Schultz et al. (1999) summarized research, conducted by a team of consultants and cooperating municipal agencies, which identified and tested eight major categories of rainfall derived infiltration and inflow (RDII) analysis methods in several diverse sewersheds. They identified metrics suitable for objective comparison of the RDII analyses, and concluded with recommendations for selecting RDII methods appropriate to a variety of applications. In the Netherlands, a very simple criterion for flooding was used to check the hydraulic behavior of a drainage system, whereas The European approach was more strict but not applicable. Therefore, van Luijtelaar (1999) presented an alternative approach to eliminate hydraulic bottlenecks in drainage systems in flat and moderately sloped areas.

Watershed Management

Controversy surrounds proposed revisions in access and recreation policy at central Massachusetts' Wachusett Reservoir, a crucial source of drinking water for metropolitan Boston (Steinberg and Clark 1999). Although tensions persist between Boston and the Wachusett region, area residents' complex valuation of the reservoir as a space of utility and a place of everyday life suggests opportunities for consensual resource coalitions and initiatives. Duram and Brown (1999) present the results of a mail survey of 64 federally funded watershed initiatives in the United States. The perceived effects of participatory watershed planning include increasing awareness of watershed conditions, heightening interagency coordination, reaching consensus on resource management plans, and lending legitimacy to final plans.

Fifty-one municipalities and county and regional agencies in the Rouge River Watershed in metropolitan Detroit, Michigan were using the "watershed approach" to solve water-quality problems from CSO, stormwater, NPS and illicit discharges (Johnson et al. 1999b). Latchaw and Jarrett (1999) described a watershed restoration strategy for an urban stream in Louisville, Kentucky that was damaged by a flood. The local flood management agency, the Louisville and Jefferson County Metropolitan Sewer District, chose to change its flood and environmental management practices to reduce similar problems in the future. Letey (1999) presented the results of a case study that illustrates the interaction between the political system and science on a water management issue. Irrigation projects in the western San Joaquin Valley, California led to a situation requiring subsurface drainage and disposal of the drainage water. The original plan was to discharge the drainage water in the Suisun Bay east of the San Francisco Bay, California. Severe damage to birds associated with selenium in the water led to a reevaluation of irrigation and drainage management options.

Norton (1999) outlines the Gulf of Mexico Program (GMP) that was envisioned as a multi-stakeholder endeavor to improve coordination among Federal and Gulf State agencies and to directly involve non-government organizations in the development and implementation of actions to address key environmental problems confronting the Gulf. The GMP works to identify and implement innovative and incentive-based approaches that support Gulf State and coastal community efforts to improve the quality of life for their citizens and their environment. Sneve et al. (1999) summarize a study by the Louisville and Jefferson County Metropolitan Sewer District (Kentucky) to develop and evaluate pretreatment program performance measures that were intended to lead toward a further reduction of pollution from industrial (indirect discharge) sources. The objective of this project was to develop, implement, and assess specific performance measures designed to measure the environmental impact of the pretreatment program in a selected sewershed or watershed. The State of Washington has pioneered the use of watershed analysis as a regulatory tool since 1992 (Sturhan 1999). The rules and methods for conducting watershed analysis were developed by Timber/Fish/Wildlife, a cooperative of the timber industry, Indian tribes, environmental groups, and government agencies. Forested basins of about 10,000 to 50,000 acres were delineated across the state, and about 60 analyses have been completed, with another 35 in process.

A successful public outreach and stakeholder involvement campaign, together with a thorough engineering investigation and planning program, was helping the City of Edmonton, Alberta, Canada develop and obtain support for a cost-effective CSO control strategy (Barth et al. 1999). The Towards A Cleaner River (TACR) campaign was developed based on a need to inform and involve the public and interested stakeholders in the development of Edmonton's CSO control strategy. Schroedel et al. (1999) described efforts to finance Wisconsin's Rock River Watershed Partnership, a broad-based stakeholder group committed to addressing nutrient and other water quality management issues. Williams (1999) described the South Dade Watershed Project that analyzes the relationship between water and land use. It tries to establish consensus with stakeholders, and develops regional planning criteria that would assure a sustainable water supply and protection of species in the Everglades National park and the Biscayne Bay, while improving urban, agricultural and natural systems for south Dade County, Florida.

Australia's 'Landcare' program was a community-based participatory program established by government to tackle the problem of land degradation. Landcare involves thousands of Australians working together in locally based groups, tackling problems of common concern. Ewing (1999) reviews how the State of Victoria has responded to these challenges and suggests what challenges remain. Concerns about stormwater pollution were relatively new in Australia, and the physical and administrative systems necessary to cope with these have not fully evolved. O'Loughlin and Robinson (1999) described the growth of these concerns and how they came to be important, dealing particularly with the Australian State of New South Wales (NSW). Stormwater management practice in NSW has developed in a somewhat haphazard manner (Robinson and O'Loughlin, 1999). The evolution of current practice was critiqued. The impact of recent government initiatives including the NSW requirement to prepare catchrnent based stormwater plans was reviewed and suggestions made. A more rational policy framework was proposed which may have additional advantages to the current arrangements.

Eckert et al. (1999) summarize a management plan for an urbanizing river in Australia. A management system, including gross pollutant traps, automatic flocculant dosing and 16 ha of lakes was designed to address many of the failings observed in similar systems. McAlister et al. (1999) summarize major scientific studies conducted in south-east Queensland that highlight the importance of stormwater runoff as a significant contributor to the degradation of the local environment that has occurred since European settlement. These studies have identified the fine sediment component of urban stormwater as a key cause to these environmental impacts. As a consequence of these studies, a 'total catchment' approach has been developed and applied to urban stormwater quality management in Brisbane. A 1996 amendment to New Zealand's Local Government Act 1974 requires local authorities to complete asset management plans (Watts and Greenaway 1999). This required the identification and locating of all assets owned and operated by local authorities, condition and performance assessments, and the definition of accurately cost estimates of levels of service for all service delivery activities. It became clear in Christchurch that commonly accepted infrastructural asset management approaches threatened to undervalue or ignore assets with natural or social values. Currently over one hundred and sixty local government agencies in NSW, Australia have a legal requirement to prepare catchment-based stormwater management plans. Brown and Ball (1999) report on their efforts to gauge and evaluate responses by stormwater managers in the process of preparing these plans.

Clifforde et al. (1999) described developments that were currently taking place towards the creation of a comprehensive integrated management capability for urban wastewater systems. The principal vehicle by which these developments were taking place was a European Union (EU) funded collaborative project led by WRc and DHI together with numerous other partners. The project comprised both technological developments in terms of procedural issues, hardware and software and extensive practical testing via a series of pilot studies. Konig et al. (1999) described some results of an integrated model application in the Hovringen wastewater system in Trondheim, Norway. The model includes wastewater production, surface run-off, infiltration, transport and treatment under a joint Matlab/Simulink platform. The model also allows the effects of real time control to be simulated. The objective was to minimize pollution discharges to receiving waters and to define design loads for the extension of the treatment plant. Bazzurro et al. (1999) described a pilot project carried out in the framework of the EU Technology Validation Project. This pilot project was related to the combined urban drainage system of Genoa's historic center that consists of eight natural streams flowing in culverts under the urbanized area. The Venice, Italy study was one of the pilots of the “Integrated Wastewater Project under the EU sponsored Innovation Program (Pretner et al. 1999). The project aims to demonstrate that an integrated approach to the planning and management of wastewater facilities was feasible and cost-effective. The project focuses on the integrated modelling of the sewer network, wastewater treatment plant and the Venice lagoon. The model will aid in optimizing the planning and management of the wastewater structures by adopting innovative monitoring and control technologies.

Musiake et al. (1999) discussed the basic concept of improving the water cycle to better support sustainable urban systems in Japan. An investigative procedure was presented that explains how to set up the project goals and how to evaluate the water cycle. Tsunoyama et al. (1999) described efforts to restore the hydrologic cycle in the Ebi River, which flows through Funabashi City in Japan. Using a physically-based distribution model, the authors studied quantitative changes in the water circulation system over time, and deduced future changes.

Sustainability. From definitions of sustainability, Rijsberman and van de Ven (1999) derived five key elements, by which sustainable development can be described. The most important differences in the approaches can be reduced to the basic attitude towards (a) people in their environment and (b) norms and values. Combining these two components leaded to four basic approaches to sustainability. The suitable definition of spatial scales of investigated systems was one of the most important questions within the water management (Stransky et al. 1999). The approach of transfer of global principles to local scale allowed determining major problems in areas investigated and establishing linkages to their causes. The urban water management objectives of ecological sustainability, economic efficiency and urban amenity required the adaptation of an integrated approach to water management. Lawrence et al. (1999) reviewed developments in the application of total water cycle based management approaches across Australia, Canada, United Kingdom and United States. The authors concluded that the need for a more integrated approach to urban water management was now being widely recognized, with a growing adoption of total-water cycle-based management, and substantial investment in ongoing studies and research related to its further application.

Loke et al. (1999a) presented a framework that attempts to give an overview of the scientific tools used in urban storm drainage to water-quality problems. It tried to clarify the structure and terminology of current engineering methods by using diagrams, namely the problem identification and management scheme, the decision-making process scheme and the actual methodology overview. Recent emphasis on citizen group or stakeholder involvement in a variety of urban stormwater related policy making situations has led to the need for the technical professional to become proficient in facilitating such groups. Reese (1999) described a series of related techniques, principles and a process that have been used successfully in a variety of stormwater-related policy making settings including stormwater financing credit approaches, rate making studies, master planning and program development. Langeveld and Wiggers (1999) look at urban storm drainage and urban sanitation, not as technical problems but as conceptual ones. This paper introduces a three-stage approach, first focusing on concepts of urban water systems by combining unit-flows (water and material flows). Then the concepts were classified, and an assessment of both the possibility and desirability of the selected concepts was made. The advocated approach offers opportunities for more appropriate urban water systems by proposing new concepts for urban water systems and by guiding existing urban water systems towards sustainability.

TMDL. Three municipal treatment plants and stormwater runoff were designated as sources contributing to the impairment of South San Francisco Bay, California (Tucker et al. 1999). The City of San Jose, California believed that the TMDL process served as an important way to engage stakeholders in the development of regional-environmental-management strategies. Mooney et al. (1999) presented a new TMDL-modeling framework for the Delaware River to accurately represent the current condition of the river. Novotny (1999) provided direction for TMDL research. TMDL methodologies and concepts have several problems, including determination of loading capacity only for low-flow critical periods that preclude consideration of wet-weather sources in water-quality management. Research was needed to develop watershed pollutant loading and receiving-water loading-capacity models that link wet- and dry-weather-pollution loads to the probability of exceeding water-quality standards. Chen et al. (1999a) presented a decision-support system (DSS) to calculate the TMDL of various pollutants for water-quality limited sections within a river basin. The DSS includes a watershed-simulation model, a database, a consensus building module, and a TMDL module that provides a worksheet for the calculations. The methodology was demonstrated with an example application in the Catawba River, Alabama.

Models

Kornecki et al. (1999) evaluated the Spatially Integrated Models for Phosphorus Loading and Erosion (SIMPLE) for predicting runoff volume, sediment loss, and phosphorus loading from two watersheds. SIMPLE tended to underestimate runoff volumes during the dormant period, from November to March. Results of model evaluation indicated that SIMPLE's predictive ability was acceptable for screening applications but not for site-specific quantitative predictions. Schwartz and Naiman (1999) derived the mean and variance of planning level load estimators under mild parametric assumptions and using a distribution free approximation. Common use of the mean, median, or geometric mean of event concentrations was shown to result, in general, in biased estimates of the mean annual load. Substantive implications for regional assessments, planning, and watershed management were illustrated with a simple example drawn from Chesapeake Bay, Maryland. Alex et al. (1999) described a system of numerical models (PLASKI, SIMBA sewer and SIMBA) for simulation of wastewater production, transport and treatment, respectively. The three modules were all running under MATLAB/SIMULINK and allow integrated simulation of processes in all three-system components.

An integrated system in Flanders consisting of a sewer, a wastewater treatment plant and a river component was selected for a modelling project (Fronteau and Bauwens 1999). The purpose of that project was to assess the impact of CSO on the receiving water and to investigate on the effects of different operating scenarios within the sewer system. Commercial mathematical models were used, i.e. both the sewer network and the WWTP were modelled with Kosim, while Isis was used to represent the river system. Brashear et al. (1999) described a project to deliver stormwater management information through the World Wide Web. The Texas Nonpoint SourceBOOK was a Web-based stormwater quality guidance document for public works professionals in the State of Texas. The SourceBOOK allowed users to access a wide variety of stormwater management information including the applicability and cost-effectiveness of stormwater management practices, legal authority issues, funding mechanisms for stormwater programs and local water-quality information. Most importantly, a database of over 100 BMP was available for users to access, allowing a diverse audience to become familiar with BMP principles and application procedures (sizing, design principles, etc.).

Real-time control. Despite considerable modeling efforts in recent years, a tool was still lacking which allows the simulation of sewer system, treatment plant and river as well as the analysis of real-time control (RTC) strategies using information from all parts of the urban wastewater system. Schutze and Einfalt (1999) and Schutze et al. (1999) presented a software package for synchronous optimization and simulation of the urban wastewater system (SYNOPSIS) that integrated the simulation of the sewer system, treatment plant and receiving water and can be used for RTC. Marti et al. (1999) described an optimization procedure for RTC of a combined sewer system in the city of Barcelona, Spain. The control system involves measuring the variables at various points, collecting the data at the control center, processing and analyzing the data, and deciding on what actions should be taken by the actuators on the basis of the real time, self-calibrating hydraulic model. Moller et al. (1999) described a predictive urban drainage RTC system, which was based on a standard urban drainage modeling tool. The potential operational benefits associated with predictive RTC were illustrated through a test case. Reda and Beck (1999) studied the impacts of CSO on river water quality using the Multiple Continuously Stirred Tank Reactor (MCSTR) dynamic model. The potential for applying this model in a real-time context was demonstrated as a tool to support decisions regarding treatment plant operation during storm events, when it was often not possible to sustain full treatment of the incoming sewage flow.

The city of Barcelona, Spain has a 1,450 km-long combined sewer system with 10 pumping stations, 16 gates and 3 holding tanks. Marques et al. (1999) presented a remote control system that enables images obtained from a meteorological radar to predict current and future rain levels in the city of Barcelona, Spain. The received images were calibrated with the remote-controlled rain gauges in real time. Vazquez et al. (1999a) examined the value of real-time management of a sewer system to reduce the impact of effluents and thus improve the quality of the host environment. The aim was to make better use of the storage capacities in the mains and tanks to reduce discharges into the environment. A multi-criteria optimization algorithm was used to provide control strategies for the components of the sewer system, e.g., sluices and pumps. Graph theory has been chosen as the mathematical tool. The study was applied to the sewer network of Saverne. Worm et al. (1999) used control strategies to equalize the hydraulic loading of a WWTP using a grey-box model of the sewer system that was based on correlation properties of flow, water level and pumping activity. The influent flow pattern showed fast transitions due to two major pumping stations in the sewer system that were operated by means of local control. By applying a stochastic flow model, calibration can be avoided since the parameters were estimated directly from the data. Hernebring et al. (1999) described the three Swedish pilot projects carried out as part of the Technology Validation Project "Integrated Wastewater" (1997-2000), supported by the European Commission.

The three Swedish projects were carried out in the cities of Helsingborg, Halmstad and Sundsvall. All three projects focus on the interaction between the sewer system and the wastewater treatment plant under variable operational conditions, created by the application of RTC in the sewer network. Pfister and Cassar (1999) described a research project that focuses on minimizing total emissions from sewer systems using RTC. The main goals of the study cover the optimum use of storage capacities, the best performance of the treatment plant, or by the dynamic management of the combined sewer system. The benefit of RTC increases if forecasted information of rainfall and runoff was taken into account.

Rainfall modeling. Luk et al. (1999) described a rainfall forecasting model that integrates an artificial neural network (ANN) with a GIS. The ANN was trained to recognize historical rainfall patterns recorded from a number of gauge of the study catchment and to make point forecasts of rainfall. The GIS was used to spatially distribute the point rainfall forecasts produced by the ANN. Mikkelsen et al. (1999) used regional modeling of a range of rainfall variable statistics to assess the performance of different historical rain time series. Sufficiently long rain series were rarely available from the exact catchment in question and for this reason simulations were often based on available rain series from other locations.

Willems (1999) reported on data collected from a dense network of rain-gauges in Antwerp, Belgium to study the stochastic structure of spatial rainfall at the small spatial scale of small hydrographic or urban catchments. The derived spatial rainfall model contains two structures: a deterministic structure for the physical description of individual rain cells and cell clusters, and a stochastic structure for the description of the intrinsic randomness in the sequence of different rain events. Durrans et al. (1999) compared a number of approaches to the problem of how to disaggregate rainfall time series using polynomial approximating functions. Results of these evaluations indicate that a disaggregation method presented by Ormsbee was a relatively good performer when storm durations were short (2 h), and that a quadratic spline-based approach was a good choice for longer-duration storms.

Useful variables for defining the state and evolution of a rain system include rainfall rate, vertically integrated rainwater content and advection velocity. The forecast model proposed in this work complements recent dynamical formulations by focusing on a formulation incorporating these variables using volumetric radar data to define the model state variables, determining the rainfall source term directly from multi-scan radar data, explicitly accounting for orographic enhancement, and explicitly incorporating the dynamical model components in an advection-diffusion scheme. An evaluation of this model was presented for four rain events collected in the south of France and in the northeast of Italy (Dolcine et al., 1999). A procedure to generate rainfall input for the EUROpean Soil Erosion Model was presented. To develop such a procedure, first of all the influence of rainfall event amount, rainfall event duration, and time to peak intensity of event rainfall on soil losses, calculated with EUROSEM, has been tested for several rainfall stations. It seems possible to produce site specific appropriate rainfall input for EUROSEM, only with the knowledge of distributions for the investigated basic rainfall parameters; however, to improve the procedure and make it practically useful, it will be necessary to account for seasonal changes of distributions of basic rainfall event parameters (Strauss et al., 1999). Gyasi-Agyei and Willgoose (1999) presented a generalized hybrid model to generate point rainfall for a wide range of aggregation levels. The rainfall process was expressed as a product of a binary chain model which preserves the dry and wet sequences as well as the mean, and a correlated jitter, a second-order autoregressive Gaussian process, used to improve the deficiencies in the second-order properties of the binary chain. Two possible binary chain models were analysed, a non-randomized Bartlett-Lewis model and a Markov chain.

Optimization models. Behera et al. (1999) present an optimization methodology for determining the design parameters (storage volume, release rate, and pond depth) of a single stormwater management pond. The methodology was extended, using a dynamic-programming procedure, to parallel catchments (each with a single detention pond). The least-cost values of pond design variables were subjected to system performance constraints, in the form of specified levels of runoff and pollution control at the outfall to a receiving water. Ndiritu and Daniell (1999a and1999b) assessed the application of varying levels of optimization on model simulation performance and parameter identification using a genetic algorithm (GA) and a 10-parameter version of the MODHYDROLOG rainfall-runoff model. Four levels of optimization were obtained through the use of two GA formulations, the traditional and an improved GA, and by varying the optimization parameters with each formulation. It was proposed that the systematic verification of the adequacy of optimization should be an integral part of model calibration exercises.

Thomas et al. (1999) described the hydraulic verification of optimal control models that have been developed for large interceptor sewer systems. Both linear- and dynamic-programming models were tested using idealized interceptor sewers. The models include a simple hydraulic verification routine in which a quasi-steady approach was used to estimate interceptor sewer water profiles at each time step in the solution. Veltri and Pecora (1999) applied genetic techniques using data measured from an urban catchment to calibrate parameters from two well-known commercial modeling tools. These genetic techniques can be successfully applied to emulate a modelling environment and subsequently to calibrate indirectly the same model. Blanpain et al. (1999) described how stochastic search algorithms to be used to more fully explain the flows in a sewer network with incomplete information on its physical characteristics. The comparison, based on hydraulic simulations, showed that their method allows reduced flow and water depth deviations by at least 50 %. Choi and Ball (1999) presented a decision support system for estimating optimum values of model control parameters. SWMM was used to simulate the runoff response of an urban catchment, while ARC/INFO and an optimization algorithm were employed to enhance spatial data handling and to optimise model control parameters.

Heaney et al. (1999b) described a new method for optimizing the design of urban storm-sewer systems. The vertical alignment design problem was defined by a set of discrete pipe diameters and costs, excavation costs as a function of soil type, and a pre-defined horizontal arrangement of pipes and manholes for a gravity sewer. Genetic algorithms were used in place of classical techniques to arrive at the least-cost solution for a specified design storm. An example was presented to illustrate the technique. Use of mathematical models requires the estimation of model parameters. Parameter optimization was preferred to the trial and error visual comparison of observed and modelled output response, due to subjectivity and time-consuming nature of the latter approach. Dayaratne and Perera (1999) described an optimization procedure to estimate the model parameters of the urban stormwater drainage model called ILSAX. The problem of optimal water distribution to a range of retention reservoirs in an urban sewer network during rainfall events was overflows and its impact on receiving waters.

Stochastic models. Lei et al. (1999) presented a new Stepwise Hypothesis Test Model Calibration (SHYTMC) procedure that includes explicit recognition of modeling uncertainty and system identifiability. Central in the SHYTMC procedure was the estimate of upper and lower bounds of the modeled output time series. A comparison with the result from 1,000 Monte-Carlo simulations suggests that the worst scenario approach was sufficient in the context of the SHYTMC procedure. Rauch et al. (1999b) outlined the background of engineering analysis and applied the methodology to a probabilistic design problem concerning CSO reduction. The geometrical data used in stormwater models were hardly ever 100 percent correct and the process data like hydraulic roughness, overflow coefficients etc. were based upon accepted average values.

Clemens and von der Heide (1999) used Monte-Carlo simulation to evaluate the stochastic nature of this uncertain input data. The uncertainty or reliability of results produced by rainfall-runoff models was a function of uncertainties in model parameters, input data, and model structure. Hoybye and Rosbjerg (1999) presented a stochastic instantaneous unit hydrograph model describing the catchment as a single linear reservoir with input and transfer functions treated as random processes. Errors in runoff predictions caused by errors in input data and model parameters were analyzed by solving the governing stochastic differential equation (SDE) analytically, thus quantifying - in a general way - the error propagation structure and the relative importance of input errors and parameter errors. Data from 34 rainstorms were selected to verify the analytical SDE approach. Monte-Carlo simulation, an approach developed for incorporating the uncertainty of parameters for estimating runoff in the design of polder systems in ungaged watersheds, was used to derive a set of realizations of streamflow hydrographs for a given design rainstorm using the U.S. Soil Conservation Service (SCS) unit hydrograph model (Yulianti and Lence, 1999).

Rainfall-runoff quantity models. Ando et al. (1999) described how the effects of urbanization on the hydrological water cycle were estimated by using a simulation model to quantify the constituent elements of the hydrological-water cycle. A questionnaire survey was conducted among residents of the river basin to identify the problems that the residents wish to have resolved through the restoration of the hydrological-water cycle in the Azuma River and to set target values for the desired improvements. Becker et al. (1999b) presented a few examples where detailed field studies described the essential elements of runoff generation and thus help to achieve a more realistic representation of the underlying mechanisms within process-oriented rainfall-runoff models.

Hromadka and Whitley (1999) developed a mathematical formalization of link-node hydrologic models using HEC-1. By subdividing a watershed into numerous subareas, and connecting the subareas by a network of links, a link-node model representation of the watershed was constructed. King et al. (1999) compared two methods of simulating excess rainfall on a large basin with multiple rain gages. The SCS daily curve number method (CN) was compared with the Green-Ampt, Mein-Larson (GAML) method on the Goodwin Creek Watershed. Li and Joksimovic (1999) presented a methodology to define the average conditions for urban drainage system modelling.

The drainage system performance should be first analyzed in a cursory manner to identify the average conditions and the "typical rainfall year". A detailed analysis of the drainage system performance should then be conducted for the “average rainfall year” and the “typical rainfall year.” If the discrepancy in performance was large, the “typical rainfall year” should be used in the analysis of average conditions of urban drainage systems. Loke et al. (1999b) compared Artificial Neural Networks (ANN) and Grey-Box Models (GBM), implementing them in three practical urban storm drainage case studies. The advantages of ANN included good generalization, high fault tolerance, high execution speed, and the ability to adapt automatically without human intervention. However, ANN relied strongly on the availability of data examples, and they were not transparent and obstruct any direct analysis and interpretation of their performance. On this basis the GBM was superior, as it enables the user to get a better insight into the involved uncertainties.

Milina et al. (1999b) showed that, for Norwegian cities, large flood events have only been affected to a minor degree by urban development whereas short-term events occurring after dry-weather conditions show a significant increase in runoff. The effects of urbanization on runoff have been studied where many catchments have yielded maximum flow from autumn and winter frontal rains, often concurrent with snowmelt or rain on frozen ground. Morita and Yen (1999) presented further developments of the conjunctive urban runoff model and focus on the interaction between surface and subsurface flow components. This interaction was directly related to the estimation of effective rainfall or initial loss of hyetographs. The model reproduced the initiation of overland flow and initial loss process and enables the estimation of the effective rainfall reasonably and theoretically.

Nania et al. (1999) designed and conducted experiments on flow patterns at street crossings and intersections. A one-dimensional formulation was proposed in order to predict the dividing flow in street crossings. Rigby et al. (1999) developed a sophisticated event based urban hydrology model from very simple beginnings. It highlighted the capabilities of earlier models and how they have increased in complexity and functionality over the last two decades. Shen et al. (1999) proposed the fuzzy neural network model called "FUZZY STORMNET" to estimate volumetric flow from rainfall intensity. This model for flow estimation could be calibrated automatically by use of known storm events, and no knowledge on the field and the sewer system was needed. Stephens and Kuczera (1999) tested the widely used time-area method at the parcel scale. The time of concentration for impervious areas at the allotment scale was found to be of the order of 2 min and not the 5 min as assumed in Australian practice. This result has implications for the design of sub-catchment scale pipes, storage basins and outflow control devices. Terayama et al.(1999) developed a stormwater runoff model based on the modified Road Research Laboratory method, to express the effects of on-site storage considering temporary storage of the effective rainfall and its disposal. An example application of this model in a local city, which has introduced the on-site storage facilities, was also presented. A nonlinear rainfall-runoff model was developed and applied to flood runoff analysis in Japan. Sugiyama et al. (1999) extended the model's applicability by developing practical equations for estimating model parameters that were appropriate on a regional basis. The utility of the estimating equations was tested by computing runoff hydrographs for lumped basins. Vaes and Berlamont (1999a) showed that a well-calibrated reservoir model can predict CSO emissions as well as a detailed hydrodynamic model, taking into account the uncertainties in the input data. Such simplified models were ideal tools to perform quickly various scenario analyses. Physically based conceptual models give an optimal balance between model uncertainty and uncertainty in the input data.

Wong and Kho (1999) studied the increase of flood peaks due to urbanization. Four urbanization scenarios were simulated and subjected to the Singapore 2-year rainfall. The degree of urbanization was expressed in terms of the percentage of developed area and the percentage of channelized area. Their results showed that the patterns of the flood peak increase for the downstream to upstream and the inside to outside urbanization sequences were concave. Wong and Li (1999) reported on a conceptual study of the hydrological effects of urbanization. By considering urbanization on an overland plane as a process whereby a relatively rough, permeable surface was gradually replaced by a relatively smooth, less permeable surface, the effect of urbanization sequence on the flood peak was theoretically assessed by the kinematic wave method.

Yen et al. (1999) presented details of the runoff model ILUCAT. The model allowed temporally variable rainfall in incremental times as input to each catchment, and deducts abstractions to yield the rainfall excess to be routed through the urban catchment. Each catchment was divided into five types of areas, namely, direct impervious, direct pervious, supplemental impervious, supplemental pervious, and noncontributing areas. The rain excess was routed through two flow paths of the first four contributing areas using the time-area method to produce the runoff hydrograph. Cagiao et al. (1999) presented two different methodologies for a study of the runoff generated in an urban watershed with a separate sewer system during stormwater events. The first approach used a process simulator (SWMM), and a non-linear parameter estimation tool (PEST), while the second used artificial neural networks. A pilot project of a subcatchment in the city of Santiago de Compostela was studied. Campolo et al. (1999) used neural networks to forecast flow rates in the Arno River downstream of the city of Florence, Italy during low-flow conditions. The model used basin-averaged rainfall measurements, water level, and hydropower production data. Model predictions were found to be accurate with root-mean-square error on the predicted river flow rate, less then 8 % over the entire time horizon of prediction. Chang and Hwang (1999) used the group method of data handling (GMDH) algorithm to evaluate complex rainfall-runoff processes in a heterogeneous watershed in Taiwan. Two versions of the revised GMDH model were implemented: a stepwise regression procedure and a recursive formula. The prediction results of the revised GMDH models and the instantaneous unit hydrograph (IUH) model were compared. Much better performance was obtained with the revised GMDH models.

Dinicola (1999) presented recent efforts to develop regionalized HSPF parameters for King and Snohomish Counties in Washington that were useful for urbanizing watersheds. Djordjevic et al. (1999) described a model for dual drainage - an approach to rainfall runoff simulation in which the numerical model takes into account not only the flow through the sewer system, but also the flow on the surface. The numerical model simultaneously handled the full dynamic equations of flow through the sewer system and simplified equations of the surface flow. The surface excess water (due to the limited capacity of inlets or to the hydraulic head in the sewer system reaching the ground level) was routed to the neighbor subcatchment (not necessarily the one attached to the downstream network node), using surface retentions, if any. Edijatno-Nascimento et al. (1999) described a new empirical watershed model that involves only three free parameters. In spite of its crude simplicity, it achieved, on average, worthwhile results on a set of 140 French catchments and overwhelmingly outperformed a linear model involving 16 parameters. It performed roughly as well as a conceptual model with five free parameters, derived from the well-known TOPMODEL.

Escarameia and Swaffield (1999) summarized the results of research on monitoring and modeling storm water runoff from roofs in the UK. This paper presented important new data for the design of rainwater systems and concludes that numerical simulations of unsteady flows were a useful tool for complementing the design recommendations in current design guides. Four simple conceptual daily rainfall-runoff models were applied to a 25-basin data set in the UK, covering a range of sizes, topographies, soils and climates (Houghton-Carr, 1999). Model performance was judged by a range of quantitative and qualitative measures of fit, applied to both the calibration and validation periods. These included efficiency, mean annual runoff, baseflow index, the synthetic monthly and daily flow regimes, and the flow duration curve. With increases in computing power of recent years, fully two dimensional, unsteady hydraulic modelling was becoming increasingly common for applications involving large, complex floodplains. Bishop et al. (1999) described the results of a recent study of a highly urbanized area along the Gold Coast, Queensland, Australia. With the increasing focus on ecologically sustainable development, and concerns regarding class actions by flood affected communities, many agencies in Australia were requiring that new proposed urban development have zero impact. With regard to flooding impacts, this requirement has resulted in the need for assessment of effects, in terms of water level changes, down to 1 cm or less accuracy. Details were provided on the requirements of and approach to full two dimensional flow modelling including the required grid definition and size, structure modelling, fine scale nesting and model stability and accuracy (Collins et al., 1999). A distributed, field-based rainfall-runoff model was developed for the 1400-km^2 arid catchment of Nahal Zin, Israel. No calibration with measured flow data was performed; the model used rainfall radar input applied over a catchment that was spatially disaggregated into different terrain types according to hydrologically relevant surface characteristics. In general, this study showedthat field-based data on generation and losses of runoff may be incorporated into a distributed hydrologic model to overcome calibration with the poor data records of arid high-magnitude events (Lange et al., 1999a and 1999b).

Zug et al. (1999a) described modeling efforts to address both flood control and pollution prevention at Gentilly, France. A mathematical model was satisfactorily calibrated and validated and was now being used to simulate the operation of the catchment area and its associated sewerage system.

Rainfall-runoff quality models. Arnbjerg-Nielsen et al. (1999) compared trends in annual loads of pollutants to receiving waters in Denmark during the past decade. For N and COD, models were suggested that explain some of the variation between and during events. However, a large residual variation was identified and possible refinements of the model were discussed. Ball (1999) presented a new approach for simulation of the transport of the soluble contaminant in urban stormwater runoff. This modeling system was based on a decoupled solution of the kinematic wave equations for simulation of the surface flows and an advection-diffusion model for simulation of the contaminant motion. Use of deicing chemicals and abrasives to provide traffic safety during winter caused water quality problems for urban receiving waters (Bartosova and Novotny, 1999). Their model was calibrated using data from the Lincoln Creek watershed (Milwaukee, Wisconsin), and verified on 30th Avenue watershed (Edmonton, Alberta). The results of simulation for chlorides, suspended solids, and lead were presented.

Carr et al. (1999a and 1999b) discussed the benefits of a time series approach which provided the information necessary for design of water quality control structures and for assessment of ecological sustainability. An advantage of the time series approach was that it provides an integrated evaluation of performance during a variety of wet-weather conditions. Chiew and McMahon (1999) presented a simple approach for estimating long-term runoff and diffuse pollution loads in urban catchments, and discussed conceptual modeling methods for simulating daily runoff and pollution loads. The modeling results for several catchments in Australian capital cities were presented. The study indicated that long-term and daily runoff can be estimated reasonably accurately using simple approaches. However, the water quality characteristic can vary considerably between catchments.

Commonly measured fecal bacteria concentrations in water and rainfall data were utilized as inputs for training a neural network model to distinguish between urban and agricultural fecal contamination present in inputs to a drinking water reservoir (Brion and Lingireddy, 1999). A neural network model was written that used bacterial and weather data to differentiate between three site classifications: urban, agricultural and a mixture. The validity of the source identification, neural network model was verified through a case study. Roadside gully pots form a common and important part of many surface water drainage networks (Butler and Memon, 1999). Their primary function was to retain larger solids from road runoff in order to minimize the problems associated with sediment deposition in downstream drainage structures and receiving waters. A dynamic water quality model has been developed to simulate these processes. Moulton et al. (1999) described NPDES monitoring for New Orleans, Louisiana. This paper asked the question, "How reliable were load estimates that were extrapolated from landuse based monitoring of small subcatchments?" The age of the developed areas was found to be responsible for differences in monitored nutrient loading from modeled runoff loads based on land use.

Collection systems models-quantity. Aronica (1999) presented a simple numerical model based on the method of continuity for flood routing in urban networks. The network was represented as a cascade of cells and the flood routing was schematized as a flux transfer between adjacent cells. Preliminary tests were carried out by means of the reproduction of flood wave propagation for some examples of urban drainage systems, both hypothetical and real. The results showed satisfactory numerical stability and an excellent computational efficiency. Barnett and MacMurray (1999) stressed the importance of correctly modeling overland secondary flow paths. At drainage network nodes such as street intersections, the distribution of outflow depends on nodal compatibility conditions, particularly when one or more of the outflow paths was steep, and large errors accumulated from the application of incorrect conditions at a succession of nodes.

Ideta and Kariya (1999) used hydraulic simulation to maximize inline storage and reduce flooding. Kleckley (1999) described estimating sanitary sewer system surcharging during wet weather using measured rainfall and flow. A rainfall-peak flow relationship was developed and used to analyze capacity improvements and the impact of rehabilitation on peak rates. This method should not be used exclusively as it does not assess the impact of rehabilitation on high groundwater infiltration. Lorenz and Weikopf (1999) presented a form of combined sewerage network storage management called the cascade technique. This technique utilized fully adjustable weirs to dynamically control the flow in the sewerage system. The cascade technique can be seen as an approach to decrease both the water pollution and the investment and operation costs caused by combined sewerage systems. Maitland et al. (1999) presented new features of XP-SWMM32, a model for complex open and closed conduit drainage systems. The application of these new and existing features of the XP-SWMM32 package to real-world drainage problems was outlined through the presentation of several case studies of representative drainage systems in the United States, Japan, and Australia.

Matheussen and Thorolfsson (1999) presented research on the simulation errors due to insufficient temporal resolution in urban snowmelt models. Storm-sewer overflow was calculated from an artificial overflow for all time resolution. Based on this research, the authors propose that snowmelt-produced runoff in urban areas should be measured and modeled with no more than a 1-hour time resolution. Merlein and Valentin (1999) investigated design features of sewer systems to increase the capacity of sewerage systems under pressurized flow. A mathematical model was used to compare the results of the hydraulic model under steady conditions with unsteady conditions as they were during a cloudburst.

Morrow (1999) outlined the hydraulic modeling requirements of a program to meet a new, demanding discharge consent standard (average of 3 spills per bathing season per outfall) at specific coastal discharge points. A program costing over $105M had to be designed, approved by the regulator, procured, built, and commissioned in a period of 15 months. Continuous simulation was the only valid way of confidently establishing the additional storage volumes required to meet the new consents. Vazquez et al. (1999b) proposed a new set of parameters for the Muskingum model for routing in a circular main in a sewer network for a wide range of lengths, slopes and diameters. A neural network was used to design the parameters of this model. This new application of Muskingum equations enables mean relative errors of less than 6 % to be obtained for the value and the point in time of the flood in the case of mains up to 6500 m long, with slopes varying from 0.5 % to 1 % and with diameters ranging from 150 to 2000 mm.

Watanabe et al. (1999b) proposed a practical lumping method for manholes under surcharged flow, in which all the water surface areas of ignored manholes were preserved in the water surface areas of the adjacent manholes. The lumping method was applied to a combined sewer pipe system in Matsuyama City drainage basin in Japan and the adaptability of the method was investigated through stormwater runoff simulations. Wong et al. (1999a) discussed the City of San Diego's (California) program for monitoring and modeling of its wastewater facilities. This sustainability concept had implications in terms of the databases, modeling tools, and applications of the model. Two key elements that were highlighted were the value of developing a custom GIS application to integrate and process data that was developed and updated by other City and County agencies, and applications of the model for both planning and operational studies that resulted in reduced capital and operating costs. During urban storms, the overloading of a sewer system or river bank overflow produced flows which were essentially routed by the road infrastructure and cause flooding of adjacent built-up areas (Hingray et al., 1999).

The evaluation of the damage suffered by these built-up areas required the determination of important hydraulic parameters of the inundation, such as the maximum water depth or the inundation duration. This paper described the hydraulic behavior of flooded built-up areas at different scales: individual plot, block of plots. Online sewer flow forecasting was simulated in this study using an autoregressive transfer function rainfall-runoff model and a recursive procedure for parameter estimation (Gelfan et al., 1999). Three recursive estimation algorithms were used: the time-invariant and time-varying versions of the recursive least-squares algorithm, and the Kalman filter interpretation of this algorithm. The sensitivity of the forecasting accuracy to the model order and to the initial conditions of the algorithm was studied using sewer flow data from the Milwaukee (Wisconsin) Metropolitan Sewerage District. In the UK, current river quality monitoring programs provide little information for management of CSO discharges, or objective assessment of their pollution impact. Balmforth et al. (1999a) described a methodology that uses existing river flow data, which was available at sub-catchment level in the UK, to identify intermittent discharges by a development of the unit hydrograph method, based on the hypothesis that intermittent discharges produce unit hydrographs that lie outside the 'normal' correlation between effective rainfall and surface runoff for a catchment.

The EPA and the Miami-Dade (Maimi, Florida) Waster and Sewer Department negotiated a Consent Decree settlement, which required them to undertake the installation and maintenance of a computerized collection and transmission system model. The "Virtual Dynamic Computer Model" has the ability to predict potential SSO resulting from peak flow conditions (Walch et al., 1999). The Metropolitan St. Louis Sewer District has responsibility for the management of stormwater drainage as well as conveyance and treatment of sanitary sewage within its boundaries. The Watershed Master Plan's hydrologic and hydraulic analyses were conducted using the SWMM (Miller and Loucks, 1999). Hsieh and Wang (1999) introduced a semi-distributed parallel surface rainfall-runoff conceptual model. To evaluate the adaptability of this model, three watersheds around the city of Taipei in

Taiwan were chosen to test the effectiveness of the model.

Collection system models-quality. Hvitved-Jacobsen et al. (1999) presented a conceptual model for wastewater quality changes during transport in sewer systems. Emphasis was on microbial transformations of heterotrophic biomass and soluble and particulate fractions of organic substrate; the inclusion of sulfate respiration in the model concept was outlined. The model was exemplified as a tool for evaluation of wastewater quality changes in an intercepting gravity sewer. The model concept was tested in gravity sewers as well as in pressure mains.

Schlutter (1999) presented a numerical model capable of simulating sediment transport in combined sewer systems. The main objectives were to model mass transport rates at the outlet from a catchment and at the same time obtaining qualitative information on erosion and deposition going on at different locations in the sewer system. An example was given of a calibration event from a case study. Watanabe et al. (1999a) described a distributed simulation model of water quality and stormwater runoff, which can simulate both open-channel and surcharged flows and at a temporal and spatial variation of runoff-water quality in the pipe systems. The proposed model consists of two well-known models: one was PWRI (the Public Works Research Institute, the Ministry of Construction, Japan) Model for water quality simulations; the other was the SLOT Model for stormwater runoff simulations.

Yagi and Shiba (1999) used fuzzy logic control and genetic algorithms to achieve improved pump operations in a combined sewer pumping station. Current pump operations could be improved by adding sewer water quality to the input variables and to the fitness function; the improved operations can reduce not only floods in the drainage area but also pollutant loads discharged to the receiving waters. Zug et al. (1999b and 1999c) presented a conceptual model for solid production and transfer in combined or separate sewerage systems called HORUS. The objective of this model was to reproduce the hydrographs, taking into account the characteristics of the catchment and the structure of the sewerage system.

Simultaneous measurements of rainfall, hydraulic, TSS and COD concentrations on nine very different catchments and about one hundred rainfall events allowed a large range of validation which can be considered of good quality.

Zug et al. (1999d) presented the results of a study whose objectives were the definition of the exceptional rain event compared to the capacity of the sewerage system and the development of recommendations for the design and operation of the sewerage system to efficiently manage most rainfall events. The measurements allowed the calibration and validation of a model (HYDROWORKS), which included hydraulics and masses of total suspended solids. Artina et al. (1999a) showed the results obtained from the ongoing investigation in an experimental catchment in Bologna (Italy), monitored in order to acquire data on the pollutant loads entering the sewer network and then spilled to the receiving stream by some CSO. These data were being used to calibrate a detailed model for both the sewer system and the river reach.

Models of controls. Hrabak et al. (1999) use three-dimensional computational fluid-dynamic (CFD) models to simulate various complex sewer and CSO components including mixing tanks, sedimentation basins, clarifiers and contact tanks. The modeling was used in lieu of physical modeling to support design. Vaes et al. (1999) described a conceptual model of storage sedimentation basins based on uniform flow, but taking into account anomalies due to non-uniform flow and turbulence. These anomalies were based on experiments in a physical model and simulations using CFD. This model can deal with time varying input and can be used for continuous simulations. Ta (1999) simulated the flow characteristics in a storm tank using CFD. The efficiency of the storm tank acting as a sedimentation basin to retain the suspended particle was evaluated using a dispersed phase model. A range of particle sizes was included to evaluate the sediment profile at the end of the storm event and the carry-over of suspended particles during the spill. Tyack and Fenner (1999) described a CFD model of a 1600 mm diameter prototype hydrodynamic separator. The result showed that the high vertical velocities within the device permit only particles with a high settling velocity to be removed, with the fine suspended solids (mostly organic) being passed forward for treatment in the WWTP.

Munoz-Carpena et al. (1999) developed and field-tested a single event model for simulating the hydrology and sediment filtration in buffer strips. The model was developed by linking three submodels to describ the principal mechanisms found in natural buffers. A set of 27 natural runoff events was used to test the hydrology component, and a subset of nine events for the sediment component. Ponce and Klabunde (1999) tested the feasibility of temporarily holding stormwater in parking lots by using a diffusion wave model of catchment dynamics. Four extreme storm types were applied to four typical parking lot sizes to assess the sensitivity of the resulting storm hydrograph to the choice of design slope. Results show the promise of parking lot storage in urban stormwater management. Ristenpart (1999) presented detailed information about a new stormwater management concept. Dimensioning and proof of performance of the different drainage structures was carried out with the help of an innovative rainfall-runoff model that was also briefly described.

Zheng and Baetz (1999) investigated a range of suburban development alternatives from an urban hydrology perspective. An analysis of design scenarios was conducted for a representative urban fringe development application, with the aid of a stormwater runoff simulation model (QUALHYMO) and geographical information systems software. In developing countries like India, the use of stormwater models for modeling and sizing detention basins has yet to acquire widespread application as a standard practice. Currently, design was carried out using the rational method, which was grossly inadequate, particularly as an abundance of sophisticated software was available. Gupta et al. (1999c) described the application of Australian software, ILSAX, for modeling the onsite detention basins for the Central Hospital catchment of Jaipur City, India.

Urban stormwater quality can be protected by maximizing the infiltration of frequent micro storms that account for the majority of the precipitation in urban areas. A proposed criterion was that the pre-development initial abstraction of precipitation should not be decreased by development. Heaney et al. (1999c) used a linear programming model, which in turn uses information from the GIS as input data, to find the mix of functional land use types that minimizes the cost of retaining the initial abstraction at its pre-development level. To assist local governments in their efforts to develop more effective stormwater management programs, Prince George's County, Maryland Department of Environmental Resources in cooperation with the EPA developed a guidance manual for an innovative alternative comprehensive approach to stormwater management referred to as LID (Coffman et al., 1999).

The site planning and design phase of land development projects presented the best opportunities for, and was critical to, reducing the impacts of development on the quality of the nation's waters. Recognizing the need for guidance in site planning and design, the San Francisco Bay (California) Area Stormwater Management Agencies Association (BASMAA) published the document "Start at the Source - Residential Site Planning and Design Guidance Manual for Stormwater Quality Protection" and a second edition in 1999 that also included guidance for industrial and commercial development. The manual communicated basic stormwater management concepts and illustrates simple, practical techniques to preserve the natural hydrologic cycle (Richman and Bicknell, 1999).

Munoz-Carpena et al. (1999) found that the performance of vegetative filter strips was governed by complex mechanisms. They developed a model by linking three submodels to describ the principal mechanisms found in natural buffers: a Petrov-Galerkin finite element kinematic wave overland flow submodel, a modified Green-Ampt infiltration submodel, and the University of Kentucky sediment filtration model. A set of 27 natural runoff events (having rainfall amounts ranging from 0.003 to 0.03 m) from a North Carolina Piedmont site were used to test the hydrology component, and a subset of nine events were used to test the sediment trapping component. Good predictions were obtained with the model if shallow uniform sheet flow (no channelization) occurred within the grass filter.

Receiving water models. Kellershohn and Tsanis (1999) used the WASP to create a three-dimensional eutrophication model for Hamilton Harbor, Ontario, Canada. Four remedial options, namely improvements to the WWTP, the CSO, industrial discharges, and removal of WWTP, CSO, and industrial discharges were examined. Improvements in the harbor's water quality were found to range from minor in the case of CSO improvements to significant in the case of WWTP improvements. Lung and Sobeck (1999) demonstrated that modeling continues to be the most cost-effective method of water quality planning and that water resource managers should apply water quality modeling on a regular basis to support the present and future needs of the watershed. They indicated that there was a need for increased use of water quality models to review the assimilative capacity of the receiving water for regulatory control and water quality management. Petruck et al. (1999) described the water quality simulation model FGSM, developed by the German Association for Water Pollution Control (ATV) to simulate major water quality parameters of a small urban stream. The FGSM appeared to be a valuable tool for assessing not only the chronic, but also the acute effects of combined sewage overflow events.

Walker and Stedinger (1999) described the movement and fate of pathogens from wastewater and dairy sources and the resulting raw water quality for New York City, New York. Manure and *Cryptosporidium* oocysts were modeled as surface pollutants and assumed to move in response to runoff events in the six watershed-reservoir systems within the Catskill-Delaware watershed. This research highlights the importance of wastewater-derived oocysts, the need for expanded research into oocyst fate in streams and reservoirs, and the concentration of oocysts in sewage effluent. Fitzpatrick et al. (1999) presented an overview of the development and application of a time-variable nutrient based emergent macrophyte model to a southern Florida Everglades wetlands system. The model formulation included the effects of nutrient concentrations on sawgrass and cattail plant growth, nutrient uptake, and nutrient composition.

Three-dimensional simulations of estuarine circulation in the New York Harbor complex, Long Island Sound, and the New York Bight were conducted using the Estuarine, Coastal, and Ocean Model (ECOM) within the framework of a single grid system (Blumberg et al. 1999). The model forcing functions consist of (1) meteorological data; (2) water level elevation and temperature and salinity fields along the open boundary; and (3) freshwater inflows from 30 rivers, 110 wastewater treatment plants, and 268 point sources from CSO and surface runoff.

Hsu et al. (1999) described a flood and inundation forecasting model to be used for flood damage mitigation. The simulated results from the river flood model and the cell inundation model were used to calculate the flow exchanges between the river and inundation area. The results were accurate enough to be used to simulate the water stage in the river and map out the inundation area for the various design rainfalls. Huberlant et al. (1999) described the Urban Pollution Management Procedure that was developed to address the problem of protecting rivers from urban stress in a holistic and cost effective way. The procedure allowed river systems to be modelled, with input from sewer overflows and sewage treatment works discharges, to enable assessment of minimum cost solutions. With the support of the European Commission, five pilot studies were carried out in different countries to test and demonstrate the effectiveness of this approach.

A new concept, transport detention time, was proposed in this paper to describe solute-transport processes. Using this concept, a new mathematical model was developed to describe BOD_5 removal in constructed wetlands. By treating a constructed wetland as a series of continuous stir tank reactors, an n^{th}-order ordinary differential equation was derived based on the principle of mass balance and convective-dispersive equation and by introducing transfer functions and Laplace transform (Chen et al., 1999b). The responses of ADAPT, a daily water table management simulation model, to variations in the principal input parameters which define hydrologic response units on a watershed were evaluated (Gowda et al., 1999b).

Geographic-Information Systems (GIS)

The integration of GIS and watershed modeling was moving hydrologic and hydraulic analysis to a new dimension (Preusch and Rezakhani, 1999). BASINS--Better Assessment Science Integrating Point and Non-point Sources, a GIS-based tool developed and released by the EPA, provided a convenient interactive framework for watershed management (Parandekar and Ranjithan, 1999). Walker et al. (1999) reported the integration of the EPA SWMM runoff model and ESRI's ArcView GIS for utilization by the City of Phoenix, Arizona for decision support concerning land-use changes and pollutant loading.

The GIS Weasel, developed by the US Geological Survey, was a graphical user interface developed to aid hydrologists and other physical process modelers in the delineation, characterization, and parameterization of an area of interest, drainage nets, and modeling response units for distributed and lumped parameter models (Kenner and Love, 1999).

Fankhauser (1999) presented an automatic determination method of imperviousness from aerial photographs. The color infrared aerial photographs and orthophotos used have a ground resolution of 25 to 75 cm. A maximum likelihood classification algorithm was applied to assign each pixel to a surface category. Classification results were then overlaid with the subcatchments to determine the imperviousness of each subcatchment. Classification and overlay were carried out with the raster-based GIS IDRISI. The accuracy of the estimated imperviousness for the entire catchment areas was within 10 %. Anderson (1999) described how hydraulic modeling, financial reporting and GIS have been integrated into a drainage management system in the city of Victoria in Australia. Butcher (1999) described a semi-lumped, GIS-based, transition matrix approach to estimate land use that was consistent with the level of complexity achievable in most watershed models. Several recent reservoir water supply projection studies were used to demonstrate a general framework for simulating changes in land use and resulting impacts on water quality. Butt et al. (1999) described a unified database for 14 Lake Tahoe Basin (Nevada) streams that included an inventory of riparian vegetation and stream morphology, using stream classification and riparian vegetation cover data sets. The authors provided detail on data collection and explain the development of the resultant database.

Calomino et al. (1999) described using GIS for large urban areas based on all the information needed for urban storm-water modeling. The GIS has been used together with a diffused rainfall-runoff model, MOUSE, to simulate a number of experimental events. Herath et al. (1999) presented a framework for rapid estimation of urban flood damage. The economic damage estimate was based on the property distribution within the inundated area, inundation depth and stage-damage functions. The stage-damage functions were derived from past flood data while the property distribution was represented in a detailed GIS. The method was applied to a recent flood in Chiba prefecture, Japan, and estimations and compared well with post damage assessments. Hijioka et al. (1999) described the use in Japan of distributed simulation for sewer systems to reduce inundation and water pollution events caused by CSO. An integrated system was developed to solve the problems of data-conversion from the existing sewer ledger data and the land use data. The values were generated using the detailed land use mesh database (10 x 10-m). The comparison of the simulation results with the existing rainfall data showed very good agreement. Preau and Ahmad (1999) described the components of a collection system model developed by the Sewerage and Water Board of New Orleans, Louisiana as part of a multi-year sewer system evaluation and rehabilitation program. The authors demonstrated how the utilization of a GIS in collecting and storing the data in a single location eased the model building and calibration process. Sieker et al. (1999) used GIS to process data related to the applicability of on-site, decentralized stormwater management.

Zech and Escarmelle (1999) described how distributed hydrologic models were promising but their development depends on the availability of high-resolution data able to represent urban features. Public databases from satellite imaging were not yet adequate. The authors investigated the possibility of using other kinds of databases designed more specifically for cartography. The advantages and inconveniences of such an approach were pointed out, based on two actual examples. According to Nelson et al. (1999), the Watershed Modeling System (WMS) was a comprehensive computer software application for watershed characterization and rainfall-runoff modeling in a graphical user interface environment. Through several GIS operations and tight integration with GIS databases, WMS enabled hydrologists and water resource engineers to perform rainfall-runoff modeling more efficiently than conventional modeling methods.

REGULATORY POLICIES AND FINANCIAL ASPECTS

Policy

WWF control policy in the United States, including the ongoing implementation of EPA's Phase II stormwater regulations, prompted a number of publications. Despite the world's most sophisticated regulatory system, and an unprecedented level of public and private investment in wastewater infrastructure, 44 % of the United State's waterways were still unsafe for fishing and swimming, largely due to urban WWFs such as CSO and stormwater discharges. Guta (1999) discussed the challenges of identifying and managing this ubiquitous source of pollution and building sustainable cities for the future. Calamita (1999) reviewed legislation that was considered in Congress, especially the CSO Control and Partnership Act of 1999 - H.R. 828 and S. 914, and the draft Urban Wet Weather Priorities Act, both of which were intended to help create wet weather uses and standards in the United States. The paper also reviewed EPA's efforts to comply with language added to their budget for this year that requires that they develop a guidance document to facilitate wet weather use reviews nationwide. EPA has made significant efforts to comply with this congressional mandate thereby greatly enhancing the prospects for wet weather use reviews nationwide. While the apparent direction of EPA's Phase II stormwater regulations due to be promulgated in September 1999 appeared to encourage the use of the watershed approach, the details in the regulation do not reflect that theme.

A comparison of the directions the Phase II regulations appear to be taking and the approach of the Rouge River

National Wet Weather Demonstration Project in Southeast Michigan was made and discussed by Cave et al. (1999). Murray et al. (1999) described the lessons learned in building institutional and regulatory frameworks necessary to accommodate a watershed approach to wet weather pollution management by Wayne County's (Michigan) Rouge River National Wet Weather Demonstration Project. Also described were the consensus building strategies that were used to engage numerous stakeholders, provide them opportunities to influence decisions, and participate in the Rouge River restoration.

Hudson (1999) discussed EPA efforts to encourage the use of decentralized wastewater treatment systems by focusing on encouraging alternative technology where appropriate, promoting management systems, and coordinating its initiatives with other ongoing efforts nationwide. The EPA Long-term CSO Control Policy "Presumptive Approach" provides guidance for specific levels of control, namely, no more than four overflows on average per year or the elimination of no less than 85 % of volume of the combined sewage collected in the entire system on an annual basis. The EPA believed that there was a general "equivalence" between the performance criteria that specify “percent capture” and the “number of overflows.” However, Morgan et al. (1999) demonstrated a wide variation between the storage controls developed under either of these criteria, and recommended that the municipalities should look at the site-specific nature of the CSO problem, and develop control alternatives accordingly.

A Natural Resources Defense Council report supported EPA’s proposed rules to clean up stormwater runoff and storm sewer discharges in small cities and noted that the proposal’s cleanup strategies have been successfully employed by more than 150 urban towns. At the same time, however, some states were complaining that the EPA proposal would undermine many state-run programs already in place (*Environmental Science & Technology*, 1999). Until now, no legal principle has been used to ensure that equity and economics were incorporated into the TMDL adoption and allocation processes. However, Clean Water Act section 305(b) may be a viable vehicle for finally including these concepts into the TMDL process (Thorme, 1999).

Stormwater discharges associated with industrial activities must be characterized for effective analysis of pollutant loads in urban watersheds. Regulatory compliance lists and inventories developed for other purposes may be poor estimators of discharging facilities. This research evaluated usefulness, flaws, and limitations of multiple forms of existing databases; then demonstrated methods to assess, combine, and correct databases to refine estimates of potentially discharging facilities in a given region (Duke et al., 1999b). This research evaluated compliance with U.S. pollution prevention regulations from stormwater discharges associated with industrial activities, focusing on facilities that had failed to complete first-stage compliance requirements ("filed") approximately 5 years after the regulations took effect (Duke and Shaver, 1999). In the City of Bergen, Norway, extensive measures against point pollution sources were implemented and to be finished before the end of year 2000 for improving the receiving water conditions. Future improvements in the receiving water quality was planned through different measures aimed at reducing stormwater-meltwater runoff which causes surface pollution washoff and CSO (Thorolfsson, 1999).

Permitting. Stormwater discharges associated with industrial activities must be characterized for effective analysis of pollutant loads in urban watersheds. Regulatory compliance lists and inventories developed for other purposes may be poor identifiers of discharging facilities and poor estimators of discharges. In 1996, the General Electric Plastics (GE Plastics) resin production facility located in Bay Saint Louis, Mississippi, embarked on a capital program to improve stormwater management at the facility by permitting and installing a structural BMP consisting of a *first flush* capture and treatment system for critical areas of the facility that had a potential to contribute acrylonitrile to stormwater discharges from the facility. Bennett et al. (1999) discussed the issues encountered during the permitting, implementation, and operation of the first flush system. A number of small cities across the United States were finding it difficult to comply with the national CSO policy issued by the EPA and have proposed alternative solutions to the CSO problem such as the site-specific designated-use reviews. In response, the EPA has begun to develop guidelines for designated-use reviews and provide technical and financial aid to several states (Mealey, 1999).

WWF control often involves unfamiliar institutional alliances, diverse groups of stakeholders, varied goals, and social or institutional resistance to new approaches. Bateman et al. (1999) reviewed the institutional framework the state of Florida has implemented to address stormwater problems associated with land uses. Karaitiana et al. (1999)

discussed a partnership between the City Council of Christchurch, New Zealand and the indigenous Moari people to sustainably manage the wetlands and waterways of Christchurch. The partners have identified six generic values, including ecology, landscape, culture, heritage, recreation and drainage, which will replace only drainage as the goals of the management approach. The government of New South Wales (Australia) has initiated a stormwater management planning program to mitigate the environmental impacts of stormwater runoff from urban areas throughout the State (Sharpin et al. 1999). The urban stormwater management plan addresses environmental protection issues, including stormwater quality, river flow, riparian vegetation and aquatic habitat management, and was tailored to the state's climatic, ecological, social, land use and administrative characteristics. Nielsen and Elle (1999) argued that current infrastructure hold a considerable momentum, and this momentum was a barrier to transformation to newer more sustainable technologies. The sewage sector in Denmark was an example of a technical infrastructure system whose technical, economic, and social momentum acts as a barrier to the implementation of small-scale storm water infiltration.

Geldof (1999) discussed the impact of "qwerties" on the implementation of source-oriented approaches to stormwater management in Holland. A qwertie was an ingrained pattern that occurs in a complex process which can be eliminated only by taking measures which have sufficient critical mass and doing so at the right moment. Nine qwerties were detailed, including those of conservatism and the use of different languages. McElroy (1999) outlined efforts in the Palestinian West Bank and Gaza Strip to develop sustainable water use and reuse practices and to improve wastewater treatment so that water quality standards and regulations can be adopted that will be meaningful, measurable and enforceable. Cooperating agencies included the Palestinian Water Authority, the Palestinian Ministry for Environmental Affairs, and The United States Agency for International Development. The development of a stormwater management strategy for the City of Clarence in Tasmania illustrated a number of difficulties faced by local government agencies and communities seeking to be more environmentally and socially responsive to ecological sustainable development goals, and the strategies available to address these difficulties. Philips et al. (1999) outlined a number of innovative approaches to the technical analysis which were used by the City of Clarence, and the principles guiding the selection of particular options. In 1994, Northern Kentucky's three counties, including 28 cities, consolidated their sewer collection systems under Sanitation District No. 1, creating the second largest public sewer utility in Kentucky, which maintained more than 1,200 miles of sanitary sewer lines. Many participating jurisdictions believe that the Sanitation District were now looking to the District to take over the operation and maintenance of Northern Kentucky's stormwater drainage systems and controls (Higdon and Eger, 1999). Because of the diverse, multi-agency and interactive nature of the watershed management approach model, both drinking and wastewater utilities often found it difficult to establish and define their role in a watershed management program. Shablen and Lauria (1999) outlined how the city of Columbus, Ohio, Division of Water and corresponding watershed stakeholders have adopted unique roles integrating federal, state and local resources to develop a source water protection partnership.

In March 1998, Portland Oregon became the first major urban area with a threatened salmonid listed under the Unites States' Endangered Species Act (ESA). This marked the first time the ESA has been applied in a major urban area and would result in new challenges in how best to apply and meet the Act. It would also require fundamental changes in a broad suite of activities conducted in planning, developing, and maintaining a city (Abrams and Prescott, 1999). The city of Indianapolis, Minnesota was currently fighting state permitting provisions that would make it illegal for the city's treatment facility to discharge combined sewer and stormwater flows without secondary treatment. The new regulations could cost the city $2 billion over the next decade (*Civil Engineering*, 1999). Odeal (1999) described efforts by the Northeast Ohio Regional Sewer District to fashion a program to develop future employees and leaders for the district, which provides wastewater conveyance, CSO control, and wastewater treatment for the Greater Cleveland area (Ohio). After years of failing to meet WWTP discharge requirements, the city of Waterton, South Dakota evaluated the existing treatment process, to determine whether or not the City was truly on a path to compliance, and to assist with making any projects affordable. Schroedel and Boerger (1999) presented the success of one of the resulting recommendations, using a program manager to track all required activities to achieve compliance. Van der Heijden (1999) discussed a system of BMP intended to reduce the phosphorus loading from an area of new development and existing commercial and mixed land use. This effort was part of the New York City Department of Environmental Protection's pilot phosphorus offset program.

Cost Analysis and Financing

Cost analysis. Onsite detention (OSD) of storm runoff decreases catchment peak flows through the routing effect of temporary storage; onsite retention (OSR) achieves the same objective by abstracting part of the urban flood wave and passing the retained water to disposal on site. Comparisons were made on the basis of site storage required (SSR) to achieve the same global peak flow reductions, environmental aspects and cost. OSR practice was shown to out-perform OSD generally in medium-large (14 ha to 210 ha) catchments with respect to SSR and, hence, cost; however, Scott et al. (1999) cautioned against use of OSR in unsuitable circumstances.

Koch et al. (1999) described an approach to the determination of flood frequency as a function of moneys that could be spent to address a road flooding problem caused by runoff from a 2-m^2 residential area near Washington, DC. Flood mitigation options included both culvert resizing and the provision of detention areas upstream. Challenges faced in completing this project included establishing a practical limit on the number of detention sites to be considered, and right-of-way issues in an area fully developed for single family homes.

Kreeger et al. (1999) presented a methodology for determining drainage system costs as the function of design storm recurrence interval. The Manning equation and sewer and swale cost data were combined to yield a relationship giving the cost per unit length of sewer or swale as a function of design flow. A typical residential development was created and a stormwater modeling computer program (Rational Method and Manning equation) along with derived cost functions were repeatedly used to design and cost the drainage system for a range of recurrence intervals.

Mangarella et al. (1999) described the retrofitting of a flood control basin in Sunnyvale California and subsequent monitoring to evaluate the pollutant removal cost effectiveness of the retrofitted basin. Costs, and particularly benefits, of WWF control were often hard to quantify. Bond (1999) examined the benefits of basic infrastructure investment - water and sanitation systems, new electricity lines, roads, stormwater drainage, and other services provided at municipal level - to South African society. The direct economic benefits of infrastructure for low-income people have long been recognized, and include construction jobs, improvements in work productivity; and the growth of small enterprises. Indirect benefits include more time and resources for women; dramatic environmental benefits, public health benefits (which require infrastructure of a sufficient quality so as to enhance rather than endanger health), and the desegregation of urban society (with respect to enhanced employment, educational and cultural opportunities). McDonald and Johns (1999) use an example from Bogotá, Colombia to demonstrate how Social Benefit-Cost Accounting (SBCA) can be used to value the benefits and costs of a watershed restoration and protection project. By addressing the benefits and costs to all stakeholders, the design of watershed management programs can be improved to achieve goals in a cost-effective manner.

Rein (1999) evaluates environmental costs and benefits of implementing vegetated buffer strips (VBS) at Elkhorn Slough, Monterey Bay, California, both to the grower and to society as a whole, as a means of capturing nonmarket ecosystem values and informing decision making. The results support installing VBS as a management strategy in an erosion-prone watershed to protect water quality and preserve soil fertility, as well as to protect economic interests.

Various authors examined the costs and benefits of new or rehabilitated sewer and storm drainage systems. Backstrom et al. (1999) compared resource use in a conventional buried pipe system and a grassed swale system. Based on usage of both physical and financial resources, the grassed swale was a more economic alternative than the pipe system in areas with moderate land prices. Hasegawa et al. (1999) presented a system for assessing the need for repair and improvement of sewer pipe networks based on; 1) Decrease in flow capacity of the sewer pipe, 2) Possibility of road collapse, 3) Sewer overflow and flooding by Infiltration/Inflow (I/I), 4) Increase of treatment cost by I/I. Hirai et al. (1999) applied the Analytic Hierarchy Process procedure to prioritize portions of a drainage system reconstruction project. This system was effective because it can take into account both quantitative and non-quantitative measures of reconstruction needs. An analysis of historical development and present status of urban drainage in Switzerland and Germany conducted by Krejci and Borchardt (1999) clearly indicated that according to identified problems the current practice was associated with a high risk of misdirected investments and was not consistent with optimum system operation. The authors identified research objectives and conclude that for the near future cost efficiency should be an important issue in urban drainage. Prato (1999) presents multiple attribute decision-making (MADM) as a means of evaluating and selecting land and water resource management systems (LWRMS). Advantages of MADM were that it facilitates community-based collaborative decision making, avoids some of the ethical, theoretical and practical shortcomings of conventional economic approaches, does not require assigning monetary values to ecological services, allows consideration of multiple attributes and was not culturally biased.

Financing. McCleary (1999) discussed the costs and savings of the stormwater banking approach adopted by DeiDOT and provided useful information regarding program implementation. Doll et al. (1999) provided examples of stormwater utilities with credits for onsite stormwater management, including credits for peak runoff controls, implementation of water quality BMP, and proper maintenance of onsite stormwater facilities.

Taxes or charges for stormwater discharges were becoming a more widespread method of funding WWF control efforts. The Augusta (Maine, U.S.A.) Sanitary District was facing a projected capital expenditure of roughly $30 million for CSO abatement alone over the next fifteen years. Recognizing that the costs for wet-weather controls could not be equitably distributed using its current system of charges, a new system was developed during 1998 and implemented in 1999 which took into account impervious areas as a means to generate appropriate levels of stormwater-based revenues (Freedman et al. 1999). Haarhoff (1999) reported on the introduction of a rainwater tax on runoff from sealed surfaces into receiving waters that was implemented by the Land (German Federal Region) of Schleswig-Holstein. The reactions of the communal authorities and their administrators responsible for the disposal of the wastewater including rainwater, and the level of success achieved by the District Water Authority in enforcing the creation of facilities for the treatment and retention of surface runoff was discussed.

CONTROL AND TREATMENT TECHNOLOGIES

Stinson et al. (1999) presented an overview of the EPA's Environmental Technology Verification (ETV) program which was established to overcome the numerous impediments to commercialization experienced by developers of innovative environmental technologies. The purpose of ETV was to provide such data and information to the customer groups that require them in order to accelerate the real world implementation of improved technology. This publication described the ETV approach and two recently initiated pilot programs for verification testing of WWF and source-water protection technologies.

A case study was reviewed which applied urban design planning for a commercial redevelopment project in the City of Vista, California involving the replacement of a 1950 concrete flood control channel into a restored natural “river walk” linear park. The proposed creek restoration would provide the focal point for an economic revitalization of the downtown area that includes restaurants, shops, and entertainment center, with the creek providing the common linkage (Phillips, 1999). Wong et al. (1999b) discussed the various issues and performance considerations associated with the comparisons of ponds and wetlands for stormwater pollution control. Ponds and wetlands were commonly used in urban design to meet a number of urban planning objectives including the management of urban stormwater for water quality improvement.

Stormwater Best Management Practices (BMP)

According to Rushton (1999), an innovative parking lot design at the Florida Aquarium in Tampa, Florida, was being used as a research site and demonstration project to show how small alterations to parking lot designs can dramatically decrease runoff and pollutant loads. Three paving surfaces were compared as well as basins with and without swales to measure pollutant concentrations and infiltration. Utilization of parking lots around Hatiiesburg, Mississippi was examined to suggest mechanisms for reducing runoff into local streams (Albanese and Matlack, 1999).

Prince George’s County, Maryland first introduced the bioretention device (commonly referred to as a “rain garden”) in 1990. Utilizing physical, chemical, and biological treatment processes within an aerobic soil media/vegetated filter system, bioretention has been shown to be highly effective in removing pollutants such as heavy metals and nutrients from urban runoff. By capturing, infiltrating or filtering stormwater runoff close to the source, the use of bioretention treatment can also restore hydrologic functions (Winogradoff and Coffman, 1999). Beginning in July 1997, the University of Virginia has been testing a vault/reservoir structure installed at a bus maintenance facility in Charlottesville, Virginia; two larger such structures were later installed in Warrenton, Virginia and were monitored between October 1997 and September 1998. Another ultra-urban BMP, a bioretention area, was installed at a high school site in 1998 and has been monitored since November 1998. A total of 22 storm events were sampled at the vault/reservoir structure sites, and 4 storms have been sampled at the bioretention site; water quality parameters examined included total suspended solids (TSS); total phosphorus (TP); chemical oxygen demand (COD), and oil and grease (OG) (Yu et al., 1999).

General stormwater control objectives and sustainable drainage design. Braune and Wood (1999) described how South Africa currently has one of the highest rates of urbanization in the world, causing a significant increase in surface water runoff and attendant increases in flooding and significant decreases in water quality. They presented a method of how the existing problem areas can be identified and ranked, and how the use of BMP can be used to reduce the impacts associated with urbanization. Cutler and Eastman (1999) described two projects in Christchurch Cith, New Zealand. The first, Regents Park, was an urban subdivision in an area with springs, open drains and a high water table. The City Council worked with the developer to naturalize and enhance the open waterways so that they added value to the landscape, ecology, drainage, and value of the subdivision. The second area, the Tranz Rail transfer yards, was a multi-million dollar development involving extensive areas of roofing and paved surfaces. They developed an integrated stormwater design approach that includes a two-stage settling/treatment/filtration system that retains peak discharges, contains contaminated spills, and alleviates downstream flooding. Hottenroth et al. (1999) examined the effectiveness of integrated stormwater management in Portland, Oregon. The stormwater program encourages innovative, non-structural pollution reduction techniques such as native landscaping, grass swale drainages, ponds, and public involvement and education. The Parkrose Pilot Project was started in 1994 to test the effectiveness of a wide range of these BMP in a small watershed in north Portland.

Iwamoto et al. (1999) described the sequence of urbanization, and associated receiving water problems in Japan. River excavation and widening were first used in the suburbs, followed by the raising of levees and overflow spillway to let flood discharges flow into temporary storage areas near rice fields. In the most urbanized areas, drainage channels and pump stations were constructed to handle the increased flows. Contrary to these historical approaches, they feel that “soft” approaches should be tried to encourage the natural benefits associated with reforestation and land consolidation. Kobayashi (1999) described changes that have occurred with development in Nagoya City, Japan. Rapid rainwater conveyance was being achieved by expanding storm sewers and pumping stations, but they were also stressing the use of infiltration facilities throughout the city area. Private infiltration facilities have not been developed as much as they hoped. The authors described an approach to constructing porous pavements; managing the decreased infiltration capacity of the pavements with time; and the needed field inspection and recovery operations to restore the infiltration capacity.

Cutler and Simpson (1999) described the challenge facing the city of Christchurch (New Zealand) to develop sustainable, aesthetically pleasing waterway environments that were environmental assets for the adjacent landowners. Designers were expected to naturalize the artificial drainage channels, or create new realigned reaches in confined urban settings A range of techniques were being applied to replace the existing drainage system with a sustainable naturalized waterway environment. Stahre (1999) reviewed ten years of different experiences pertaining to sustainable stormwater management in the city of Malmo, Sweden. A basic element in sustainable stormwater management in Malmo was the involvement of ecological processes in drainage and that the technical design, to a great extent, was adapted to the prevailing local conditions.

Zhang et al. (1999) stated that, although separate sewer systems usually were not designed to take full advantage of available NPS controls, a great improvement can be achieved by combining a number of separate control options. Thorolfsson and Sekse (1999) reports that the green trend in urban stormwater management, as demonstrated in the Birkeland test basin in Bergen, Norway, utilizes the capabilities of nature to store huge stormwater and snowmelt volumes and to reduce the pollution content in the receiving water. Thorolfsson (1999a) further described the Sandsli system (an alternative drainage system demonstrated in Bergen, Norway) used for drainage management in the north Atlantic. The goal was to manage the total urban runoff (wastewater, stormwater, and snowmelt) in a way that environmental damage was avoided, and the goals for the receiving water were achieved at reasonable costs. Thorolfsson (1999b) described how non-contaminated runoff was to be handled near the source by percolation and/or detention, while the polluted runoff will be collected and conveyed to an appropriate site for treatment and discharge.

McAlister et al. (1999) found that the fine sediment in urban stormwater was a key cause to many receiving-water impacts. As a consequence of these studies, a total catchment approach has been developed and applied to urban stormwater quality management in Brisbane city (Australia). Mehler and Ostrowski (1999) found that an economically and ecologically sound combination of centralized and source area control measures will be a concept of the future of stormwater management in Germany and elsewhere. Holz (1999) described how engineering solutions have not been effective at avoiding the degradation of receiving waters in the northwest of Washington's Pacific costal region. They concluded that "hard" engineering methods have little chance of mimicking the stormwater runoff attenuation of forest cover, regardless of storage provided, and that another paradigm for development must be adopted (in contrast to the present "clear, grade, and pave" approach that has not been proven to be mitigatable).

BMP effectiveness. Roesner and Brashear (1999) reported that over the last ten years, a number of BMP manuals have been developed to address the control of urban runoff for receiving water quality protection. They concluded that there was a lot of ignorance in the scientific community about what constitutes a properly designed BMP and what it really achieves, with respect to environmental protection. They therefore recommend a design criteria development approach that can be applied over a wide variety of climatologic, topologic, and geologic conditions to protect receiving waters systems. Roesner (1999) further believes that the conflicting opinions on the effectiveness of various BMP result mostly from: 1) there was no accepted uniform design criteria for BMP; and 2) the objectives of the management practices differ between authors.

Buffer corridors. Crifasi (1999) gave a description of Boulder's (Colorado) instream flow and riparian zone management program, where extensive, high-quality wetlands and riparian areas exist along south Boulder Creek. South Boulder Creek's riparian corridor contains plains riparian cottonwood forests, willow shrublands, freshwater marshes, and alkali wetlands that provide refuge for two federally threatened species, plus other rare species of plants and animals. Haberstock (1999) presented a method used to determine optimal riparian buffer widths for Atlantic salmon habitat protection in Maine. Zone 1 (no-cut zone), closest to the stream, has a fixed width of 35 ft in which no disturbance to soils or vegetation should occur. Zone 2, landward from zone 1, was a variable width zone where only limited uses that do not compromise the desired functions of zone 2, such as light tree harvesting and light recreation, should occur. Resulting total optimal buffer widths (zone 1 plus zone 2) range from a minimum of 70 ft to a maximum of more than 350'. In rare cases (e.g., extensive slopes > 25 %), optimal buffer widths can be 1,000 ft or more. The rehabilitation of urban stream channels to protect Pacific Northwest salmon runs were described by Henshaw (1999). In an effort to bolster the survival of salmon returning to the local streams to spawn, land managers have begun extensive programs to rebuild or rehabilitate appropriate habitat that has been lost or degraded due to urban development. Although rebuilt habitat in a stabilized urban stream may not provide the level of ecological integrity required to maintain endangered salmon and other stream biota, physical stability was likely one necessary component of a healthy stream. O'Neal et al. (1999) described hydraulic and biological effects of large woody debris (LWD) and an engineered wood alternative for stream channel rehabilitation projects in the state of Washington. The engineered structures consist of an interlocking complex of small diameter poles that can be carried by hand and assembled on site. The artificial structures have a high hydraulic and surface roughness to trap sediment and debris and caused variations in the pattern of water flow and resultant scour compared to natural LWD. No statistically significant differences were observed in the biological communities associated with these structures compared to LWD.

Stormwater beneficial use. Argue and Pezzaniti (1999) investigated the harvesting of stormwater to replace water supply mains for the irrigation of areas landscaped with grass, flowerbeds, and shrubs in Adelaide, South Australia. Four categories of catchments were recognized according to their levels of pollution production - roof runoff and "low", "medium" and "high" pollution runoff surfaces. Large roof areas draining to gravel-filled trenches provide passive irrigation for grassed surfaces, for example. Dillon et al. (1999) described the development of "new" water resources by using aquifer storage and recovery of stormwater. The reuse of reclaimed water through storage aquifers can lead to more environmentally sensitive design, with reduced requirements for imported water, reduced exports of sewage and stormwater, and lower water supply costs. Dixon et al. (1999) demonstrated the water saving potential of domestic water reuse systems using greywater and stormwater. Monte-Carlo modeling results show that changes in household occupancy, roof area, appliance type, and storage volume, affect the water saving efficiency of a reuse system. Fox (1999) also described a watershed approach for integrated water reuse. Zaizen et al. (1999) described roof-runoff reuse at domed stadiums in Japan, as part of a wider program for preserving hydrologic cycle characteristics in urban areas. Tada et al. (1999) investigated three alternative storage methods that can be used to assist stormwater reuse. The best method (Type-1) uses a small tank to separate "first-flush" runoff nonpoint pollution loads from the remaining discharges. Type-2 has an overflow weir to separate polluted runoff stormwater, while type-3 has an orifice to separate un-polluted stormwater into the utilization tank. Pratt (1999) described the use of storage reservoirs under permeable pavements for stormwater treatment and reuse. Permeable surfaces for roads and footpaths have been used as a means of disposal of stormwater in developed urban areas and undersealing them to enable them to retain stormwater for reuse for non-potable uses was feasible. However, the stormwater may be degraded where the pavement was used for car parking. Tredoux et al. (1999) described the Atlantis Water Resource Management Scheme that uses artificial recharge of urban stormwater and treated wastewater to augment natural groundwater. The important element was the separation of the stormwater into components of distinctly different quality. Residential and industrial urban runoff was separated into baseflow and stormwater components and utilized for various appropriate purposes.

Public education. Mashiah et al. (1999) found that raising community awareness of stormwater impacts was a critical component of an effective stormwater management program. The campaign included television advertising, newspaper and radio advertisements, displays, free environmental audits for local businesses, and a stormwater ambassador program for local schoolchildren. Heremaia (1999) described the public stormwater education program used as part of the Christchurch (New Zealand) integrated environmental planning program. The successful pilot program included the development of a web site, audio conferences, a competition, and a drama production. Young and Collier (1999) described the research-based stormwater education of the New South Wales (Australia) Environment Protection Authority. This education program was unique in Australia by providing a comprehensive, integrated, and continuing research-based strategy for involving the community in preventing stormwater pollution.

Litter/floatable control. Armitage and Rooseboom (1999) summarized the results of three years of laboratory investigations sponsored by the Water Research Commission of South Africa into the movement of urban liter through potential trapping structures. They found that once the litter has entered the drainage system it was difficult to remove. They concluded that declined self-cleaning screens showed the greatest promise for the removal of urban litter from most stormwater conduits and streams in the less developed countries. Newman et al. (1999) reported that the City of New York has improved its ability to control one source of floatables and possibly other pollutants to New York Harbor through its newly implemented “Illegal Dumping Notification Program.” This program takes advantage of one City Department’s field presence to gather and transmit valuable information to another City Department for enforcement and cleanup. They found that this program likely will reduce the number of illegal dumping sites by 15 %. Phillips (1999) described how the State Government of Victoria (Australia) provided funding to develop a litter trap (the In-line Litter Separator, or ILLS). The ILLS can be retrofitted into the drainage system downstream of shopping areas.

Catchbasins/grit traps. Grey et al. (1999) summarized the role of catchbasins in the CSO floatables control program in New York City. There were approximately 130,000 catchbasins, distributed over 190,000 acres, in New York City. They found that catchbasins were simple and very effective in controlling floatable material at the source. The most important aspect of catchbasin designs for floatables removal was the presence of a hood that was hung over the basin’s outlet. Several studies conducted in the City have shown floatable retention efficiencies of 70 to 90 %. Catchbasin hoods were also very cost-effective controls at a cost of about $100 per acre. The City implemented a catchbasin inspection, mapping, cleaning, and hooding program as part of its CSO control program. Siegel and Novak (1999) reported on the activity of the microbial larvicide VectoLex CG (R) (*Bacillus sphaericus*) for the control of mosquitoes in 346 tested Illinois catchbasins. The tests were deemed successful.

Washbusch (1999) reported on an extensive evaluation of a proprietary urban stormwater treatment unit (the Stormceptor) in Madison, Wisconsin, conducted by the United States Geological Survey (USGS) and the Wisconsin Department of Natural Resources (WDNR). The evaluation was conducted on a 4.3 acre city maintenance yard site over 9 months and for 45 runoff events having rainfall depths ranging from 0.02 to 1.31 in., plus some snowmelt influence from imported snow to the maintenance yard. About 90 % of the runoff was treated by the unit, and the remainder flows bypassed the unit during periods of high flows. The overall effectiveness of the unit was 33 % for suspended solids, 17 % for total phosphorus, 34 % for total PAH, and from 20 to 30 % for most heavy metals. In general, dissolved constituents were unaffected by the unit. Performance during the early spring events was degraded by high saline snowmelt water, which had elevated conductivity from on-site deicer storage, that significantly slowed particle settling.

Grass swales and grass filter strips. Ellis (1999) described the benefits and problems associated with directing roadway runoff to a roadside swale/infiltration system. He summarized the range of pollutant removal efficiencies achieved by vegetative BMP and reviewed available design procedures for grass-lined swales and constructed wetlands for the United Kingdom. Gharabaghi et al. (1999) described how rolled erosion control products have proven to be successful in reinforcing vegetative channel lining systems and improving their performance in erosion and sediment control. Mendez et al. (1999) summarized the results from an 18-month field experiment that was conducted to evaluate the effectiveness of grass filter strips in removing sediment and various nitrogen species from runoff. They found that the grass filters reduced contaminate yields from 42 to 90 % and concentrations from 20 to 83 %, depending on length and nutrient specie. Boubakari and Morgan (1999) tested the effectiveness of growing *Festuca ovina* and *Poa pratensis* on contour grass strips for erodible sandy loam soil on steep slopes. The *Poa pratensis* was less rigid and became flattened under submergence in the later part of the storms and was therefore not very effective in controlling erosion on the steepest slope tested (29 %).

Filtration/sorption. Sansalone (1999) conducted detailed tests of a partial exfiltration trench (PET) for passively treating highway runoff at a test site in Cincinnati, Ohio. Runoff treatment in the PET occurred primarily by sorption and filtration. Media in the PET was expected to last more than 10 years. The mass pollutant removal efficiency generally exceeded 80 % during the one year of tests. Exfiltration from the PET to clayey glacial till soils also exceeded 30 % for some runoff events. Stephenson et al. (1999) also described a pilot-scale stormwater runoff treatment system for highway runoff that used peat, sand, and rock to remove contaminants by sedimentation, filtration, and adsorption. Field-testing sites were located in Knoxville, Tennessee, and Frederick, Maryland. The primary goal of this investigation was the development and evaluation of practical remedial measures for treating highway runoff draining into sinkholes, where very rapid movement of surface runoff to the groundwater can occur. Urbonas (1999) presented a detailed description of the design approaches needed for effective sand filtration of stormwater. The approach uses the unit processes known to exist in urban stormwater runoff and within filter devices. According to Shaver (1999b), the suggested design was based on hydraulic capacity of the filter media, which, in turn, was a function of the total suspended solids removed by the filter. Shibata (1999) reported on the performance characteristics of pipe installations with replaceable filters. The data collected included information on the quantity of sand and gravel trapped in the filter section, as well as the ability of the filter to concentrate pollutants from storm water runoff.

The Multi-Chambered Treatment Train (MCTT) was developed for removal of stormwater toxicants from critical source controls (Pitt et al.,1999). The MCTT was an underground device that has three main chambers: an initial grit chamber for trapping of the largest sediment and release of most volatile compounds; a main settling chamber (providing initial aeration and sorbent pillows) for the trapping of fine sediment and associated toxicants and floating hydrocarbons; and a sand and peat mixed media "filter" (sorption-ion exchange) unit for the reduction of filterable toxicants. A typical MCTT requires between 0.5 and 1.5 % of the paved drainage area, which was about one-third of the area required for a well-designed wet detention pond. The research report described extensive development of the MCTT, including much stormwater treatability information that can be used by others who want to enhance performance of conventional stormwater control devices. A pilot-scale unit was tested in Birmingham, Alabama, at a large parking lot. During monitoring of 13 storms, the MCTT was found to have the following overall median reduction rates: 96 % for total toxicity, 98 % for filtered toxicity, 83 % for SS, 60 % for COD, 40 % for turbidity, 100 % for lead, 91 % for zinc, 100 % for n-Nitro-di-n-proplamine, 100 % for pyrene, and 99 % for bis (2-ethyl hexyl) phthalate. Corsi et al. (1999) reported the results of a full-scale test of the MCTT at a public works yard in Mileaukee, WI, conducted by the USGS and the WDNR. Monitoring of 68 common and toxic constituents was conducted during 15 storms having rain depths ranging from 0.17 to 1.4 inches in depth, over a five-month period. Very high reductions were found for all particulate-associated pollutants (reductions of 98 % for SS, 88 % for total phosphorus, and 91 % for total ZN, for example), and somewhat less reductions for dissolved pollutant fractions (13

% TDS, 78 % dissolved phosphorus, and 68 % for dissolved ZN, for example). The WI DNR also conducted a full-scale test of an MCTT at a 4-acre municipal parking lot at Minocqua, in northern Wisconsin, with similar high level removals noted.

Airport deicer control. Periello et al. (1999) described a biological treatment system for treating stormwater runoff that was contaminated with de-icing fluid at the Syracuse (New York) airport. During winter deicing operations, spent deicing fluid, combined with storm runoff, was collected and held in large treatment lagoons. When warmer weather arrives and deicing operations cease, the collected deicing fluid and combined stormwater runoff (deicing runoff) were treated in aerobic lagoons to reduce the BOD in the deicing runoff to levels suitable for discharge to the local receiving waters. Safferman et al. (1999) studied the treatment of stormwater contaminated with ethylene glycol originating from airport deicing operations using a bench-scale subsurface microbiological contactor. Zitomoer et al. (1999) discussed the use of anaerobic co-digestion of aircraft deicing runoff and municipal wastewater sludge. The high COD runoff can lend organics for increased methane production and the oxygen demanding constituents in propylene glycol deicing fluid were found to be readily converted to methane, with neither effluent BOD_5 nor TKN concentrations higher in co-digestion systems as compared to a conventional digester. They concluded that existing municipal digesters could be employed to convert the seasonally-generated deicing fluid organics to methane that could be used to run equipment or generate electricity.

Stormwater Infiltration

The behavior of heavy metals (Cd, Cu, Zn, Cr, Pb), nutrients (organic C, P, and N parameters), and major ions were investigated during percolation of roof runoff water through an artificial infiltration site. The concentrations of various components were determined in rainwater, roof runoff, and infiltrating water at various depths in the soil (Mason et al., 1999c). Permeable surfaces for roads and footpaths have been used as a means of disposal of stormwater in developed urban areas. Such surfaces provide an alternative to impermeable concrete or tarmacadam surfaces which would otherwise produce rapid stormwater runoff leading to possible flooding and degeneration of receiving water quality through the uncontrolled discharge of polluted urban waters. A further advantage may be obtained from such constructions by undersealing them so as to retain stormwater for reuse for non-potable uses

(Pratt, 1999).

According to Anderson et al. (1999), permeable pavements and similar stormwater control devices have not been exploited in the United Kingdom, in part because their adoption has been hindered by a lack of detailed knowledge of their hydrological performance. A range of simulated rainfalls, which varied in intensity and duration, was applied to the permeable model car park surfaces and monitored over an 18-month period. Results demonstrated that evaporation, drainage and retention in the structures were strongly influenced by the particle size distribution of the bedding material and by water retention in the surface blocks. Argue and Pezzaniti (1999) researched stormwater management adopted in Adelaide and declared a focus on harvesting of stormwater to replace mains water in irrigating areas landscaped with grass, flower beds and shrubs. Four case study examples of systems involving appropriate treatment trains were described, each one delivering harvested stormwater suitable for irrigation.

Given the characteristics of urban surfaces, and notably the amounts of the different pollutants that stormwater was likely to contain, an experiment was carried out in Valence (France) on two infiltration facilities, in order to assess the impact of intentional stormwater infiltration systems on the soil, and on groundwater. Stormwater from impervious urban areas can adversely impact water quality and quantity. The PET was a control device designed to moderate both the quality and quantity of urban runoff (Li et al., 1999). Urban stormwater often contains high levels of traffic-generated metal elements and particulates. These constituents were transported by stormwater runoff to surficial soils, drainage systems and receiving waters; Sansalone (1999) summarized the in-situ field-scale performance of a passive treatment system called a PET for source control of these constituents. Two infiltration trenches were constructed in a densely built-up area in central Copenhagen and equipped with on-line sensors measuring rain, runoff flow from the connected surfaces and water level in the trenches. Warnaars et al. (1999) described the field site, the measuring system and the results from an initial soil survey. There were numerous reasons, such the saturation of the existing downstream sewer system or its concentrate discharge impact on the receiving water, for using stormwater infiltration systems. However, their feasibility within an urban development project depends on physical soil characteristics and contamination risk, and also on socio-economic considerations

(Alfakih et al., 1999).

Sediment transport was studied in non-submerged overland flow over grass in a laboratory. Artificial turf (astro-turf) was used to simulate natural grass and no infiltration was allowed at this stage of the investigation. Experiments were conducted for different grass densities, flow rates, sediment inflows, and sediment types (Delectic 1999).

Utilization of parking lots around Hatiiesburg, Mississippi was examined to suggest mechanisms for reducing runoff into local streams (Albanese and Matlack, 1999). Suarman et al. (1999) reported a laboratory simulation study, supplemented with information from field installations, in which four paving sub-structures were subjected to sediment loads equivalent to those which could be expected below porous car park surfaces in stable, fully-developed residential neighborhoods in Adelaide, South Australia. Brough (1999) outlined the development philosophy behind the use of ground soakage (construction of soil adsorption basins), and discusses the procedures that have been used in the design of the basins at residential, industrial sites.

Peak flow reduction and aquifer recharge. Infiltration devices were installed in existing housing areas as a means of reducing the peak flow in a combined sewer system. The resulting economic benefits of the retrofit, especially as compared to the installation of a new sewer, were discussed by Simon and Terfuchte (1999). Watts et al. (1999) reported on the utilization of infiltration and groundwater recharge as part of an overall management strategy for Christchurch, New Zealand's waterways and wetlands. The infiltration devices used in the Upper Heathcote catchment included a separate infiltration system for roof drainage, grass swales for non-roof stormwater runoff, infiltration basins and storage of excess runoff for later infiltration. Flood control was also suggested as another benefit of planned infiltration. Yura et al. (1999) demonstrated the effects of a well-maintained infiltration facility on the volume of stormwater runoff from a large-scale housing site. In addition to flood control, the infiltration basin also had other positive effects: groundwater recharge, emergency water storage, and the control of pollutants in stormwater. Oka and Nakamura (1999) used a kinematic wave model in combination with GIS data to demonstrate basin scale effects of storm and infiltration on flood control. Rauch et al. (1999c) evaluated an integrated drainage system and simple deterministic models for modeling this system in an Alpine area. The results revealed that the simple models worked well for simulating the system over a long period of time, and that infiltration was recommended, especially when compared to conventional detention ponds. Nawang et al. (1999) compared 1-D nonlinear PDE model results for water level profiles, outflow and stormwater profiles with laboratory investigations. The results were used to development infiltration design practices for tropical conditions, specifically for Malaysia.

Investigations by van der Werf et al. (1999) in Adelaide, South Australia, demonstrated that infiltration of roof runoff could occur through clay soils overlying a shallow sandstone bedrock even when the cumulative rainfall was significantly greater than the average annual rainfall. Barros et al. (1999) tested the same premise under laboratory conditions using laboratory columns with a shallow bedrock base, an intermediate soil layer (sandy loam and a silty clay loam) and a stone cover layer. The infiltration capacity of the soil layer was found to control the fraction of rainfall that becomes surface runoff. Pitt et al. (1999) investigated the effects of soil type, antecedent moisture content, and soil compaction on the infiltration rates of water. Compaction had the greatest effect on infiltration through sandy soils, while moisture content and compaction affected infiltration through clayey soils. Age since development tests showed that some infiltration capacity could be recovered over time even in severely compacted soils. King et al. (1999), using the Soil and Water Assessment Tool (SWAT) model, compared the Green-Ampt Mein-Larson (GAML) method with the SCS daily curve number (CN) for their abilities to predict runoff volume from the Goodwin Creek watershed. For this large watershed, the curve number method generally underpredicted surface runoff volumes, while no pattern of over- or under prediction was seen with the GAML method. Yu's (1999) comparison of the Green-Ampt model and a spatially variable infiltration model showed that the Green-Ampt model consistently underestimated the infiltration rate when the rainfall intensity was high. The measured rainfall and runoff rates showed a positive relationship between intensity and infiltration rate, indicating a spatial variability in the infiltration capacity and making the spatially variable model a better predictor of infiltration rates.

Infiltration installations for pollutant removal. Pagotto et al. (1999) reviewed the information currently available regarding the ability of infiltration systems to remove pollutants from water, and including the various physical, chemical, biological and microbiological processes that occur in the unsaturated and saturated zones of the soil profile. A study on highway runoff was performed in Germany by Dierkes and Geiger (1999). They tested soil profiles and collected water samples at different soil depths for lead, zinc, copper, cadmium and PAH and found that the highest concentrations were found in the top 5 cm of soil and within two meters of the street.

Dupre et al. (1999) used ultrafiltration at different pHs to investigate the affinity of certain metal ions to form humate complexes in natural waters with a high dissolved organic carbon concentration. The log K constants for sorption to organic colloids (metal-humate complexes) were as follows: Al, Ga, Fe, Th, U, Y, Re (more than 7) >> Cr (5.5) >> Co (3) > Rb, Ba, Sr, Mn, Mg (approximately 2). The tendency of these metals to bind to organic colloids in water should be similar to their ability to bind to organic soils in the vadose zone during infiltration or to organic filtration media in a stormwater filter. Pitt et al. (1999) described adding compost to the natural soil in an infiltration system to improve both the flow and pollutant removal characteristics of the system. When compared to a natural soil infiltration area, the compost-amended soil system significantly increased the removal of both the quantity of surface runoff and the concentrations of many toxicants typically found in urban runoff. The drawback to the compost amendments was the increased nutrient loads in the system effluent. King and Baloph (1999) modeled the runoff losses of nitrates and pesticides from a golf course turfgrass using four irrigation schemes: normal and reduced water application using potable water and normal and reduced water application using reclaimed water. They showed that nitrate losses were significantly affected by the reduction in irrigation water volume, although the pesticides losses were not significant between irrigation strategies. Sansalone (1999) proposed using an oxide-coated sand in a PET to treat urban runoff. Sansalone and Hird (1999) investigated the one-year performance of the partial exfiltration reactor (PER) in removing heavy metals from highway runoff. The tested prototype was able to infiltrate 10 to 30 % of the highway runoff while removing at least 75 % of the heavy metal load from the stormwater. Hebrard and Delolme (1999) demonstrated that a biofilm of *Pseudomonas putida* on sand could significantly enhance zinc removal from runoff percolating through the vadose zone when the influent concentration ranged from 2 – 20 ppm.

Porous pavement. In order to develop design guidelines for using permeable pavements in parking lots, Andersen et al. (1999) investigated the pavement's hydrological/hydraulic behavior and its impact on evaporation and drainage during a range of simulated rain events and interevent periods. They determined that, for a one-hour, 15-mm simulated rainfall, an initially dry pavement could contain and infiltrate approximately 55 % of the water, while an initially wet structure could retain approximately 30 %. The ability to infiltrate significant quantities of runoff, especially as compared to asphalt, was confirmed by Booth and Leavitt (1999) in an experimental facility. Pratt (1999) reviewed existing information on water quantity and quality below porous pavement structures and suggested collecting the water that infiltrates through porous pavement structures for use in non-potable applications such as flushing toilets. The reuse of infiltration water below a porous pavement structure was applied at a Youth Hostel in the United Kingdom and details of the design were provided in the article.

Bond et al. (1999) reported on a 13-year study of permeable pavements in the United Kingdom. They found that microbial degradation of pollutants occurred in the pavement and that the addition of nutrients every three years was sufficient to support the microbial population. The retention ability of a 50-year old porous pavement structure and the soil below was investigated by Legret et al. (1999) and was modeled by LEACHM. Lead, copper, and zinc were not found in significant quantities in the soil below the pavement, i.e., surface retention of those metals, while cadmium was found to have migrated to a depth of 30 cm below the pavement.

Design and maintenance guidelines. Hamacher and Haubmann (1999) compared infiltration as part of a decentral stormwater discharge program to the more traditional method of rapid removal of stormwater from an area through a planned drainage system. They provided information in the article about stormwater disposal through infiltration, including construction, maintenance and system costs. In Stockholm, infiltration was included as part of an overall stormwater drainage plan. Bennerstedt (1999) reported on the Stockholm plans, including the financing of the stormwater drainage system. Hasegawa et al. (1999) described the data collected during the installation of infiltration systems in Japan and that collected by seven governmental entities on the performance of existing infiltration systems. They also proposed a qualitative method for evaluating the applicability of infiltration for flood control and environmental protection. Argue (1999) described many of the misconceptions about stormwater infiltration systems and proposed design limits and practical advice for dealing with these concerns. Noki et al. (1999) outline some of the current research on infiltration and their application to establishing proper maintenance procedures.

Alfakih et al. (1999) described how siting of infiltration facilities was dependent on physical soil characteristics, groundwater contamination risk, and socio-economic considerations. Their paper provided an overview of feasibility and design criteria for infiltration systems, including a review of currently available models and approaches. Zimmer et al. (1999) argued for the use of physically based models to design infiltration systems, rather than the traditional approach of using a design storm to calculate the required storage volume. They developed diagrams which allowed the designer to read the necessary storage volume for the infiltration system once the soil's hydraulic conductivity was known. Gautier et al. (1999) reported on the progressive clogging of three infiltration facilities and used the results to develop a model for predicting the effect of clogging on the hydraulic behavior and pollutant removal ability of the basins. Todorovic et al. (1999) also evaluated the impact of clogging on the hydraulic performance of infiltration basins over time. They successfully tested their methodology for sizing an infiltration trench/soakaway for the Miljakovac catchment in Belgrade. Laboratory testing using a simulated colloidal suspension was performed by Raimbault et al. (1999) and showed that clogging began with the application of only a small amount of clay. The wetting-drying cycle typically seen in infiltration basins increased the amount of clay retained in the upper layers of a soil and decreased its hydraulic conductivity.

Combined Sewer Overflow/Sanitary Sewer Overflow Control

Riverine litter occupies a spatial and temporal position in any systematic analysis of river systems and was a problem that was increasing in scale. Quantifiable source factors of litter in the river Taff, South Wales, United Kingdom, system were found to be mainly two - sewage inputs through CSO and fly tipping Whilst sewage-derived material constituted approximately 23 % of all items on the river Taff, large quantities of waste, especially plastic sheeting, originated from fly tipping sites (Williams and Simmons, 1999). Balmforth et al.(1999b) developed and tested a new design procedure for the control of aesthetic pollutants at CSO points. If the storage in the rain water tanks can be used to flatten the rain water runoff, rain water tanks can have an additional benefit. The effect of rain water tanks on the CSO emissions was therefore investigated with a reservoir model. Compared with storage in the combined sewer system or at the overflow, storage in rain water tanks will be more efficient in reducing the overflow emissions (Vaes and Berlamont, 1999b).

The use of sand and other media filters was gaining acceptance in the held of urban stormwater structural best management practice. Much work has been done to develop local design guidance, such as in the State of Delaware and in Austin, Texas. The suggested design of the media filters for stormwater runoff treatment was based on hydraulic capacity of the filter media, which. in turn, was a function of the total suspended solids removed by the filter (Urbonas, 1999). Walesh et al. (1999) provided a discussion of the use of on-street storage as an effective means to control stormwater runoff. It focuses on the success achieved by using street storage in two communities in Illinois and includes a description and evaluation of how this technology eliminated surcharging and basement flooding, complied with regulations and proved to be a cost-effective solution which earned public support.

As a demonstration project, the Auckland Regional Council had designed and constructed a filter device to treat stormwater from a 3000 m^2 carpark. Eight sand filters were installed in 1993 to provide stormwater treatment at a new Alaska Marine Lines, Inc. barge loading terminal along the Duwamish River in Seattle, Washington (U.S.A.). Constructed according to the "Delaware" design, each consists of a settling chamber where relatively large solids can settle before the flow passes over the weir onto the sand for filtering. A performance study monitored the flow rate through two sand filters and the water quality of inflow and outflow (Horner and Horner, 1999). Because the Urban Community of Bordeaux had been hit by important floods in 1982, it was decided to set an efficient management system to control stormwater flows. Studies have showed the significant impact of discharged effluents on the environment, especially with regard to the contribution from CSO. Therefore, it was of importance to improve the management of the sewer system during rain weather and to foresee the design of new storage structures and new treatment plants to integrate the environmental protection target (Briat et al., 1999).

Overviews of WWF controls were provided by two papers. Buriean et al. (1999) summarized a comprehensive historical literature review, highlighting the development of WWF management from ancient times to the present. The relationship between past developments, the current state, and the future of WWF management were addressed by identifying several lessons learned. Barner (1999) discussed the problems associated with stormwater management in a karst terrain in Springfield, Missouri. The lack of recognition of sinkholes as integral parts of dynamic hydrologic systems may result in problems with on-site/off-site drainage.

CSO control planning. Bontus et al. (1999) described Edmonton's proactive long-term CSO control plan, which brought the opinions of stakeholders, including Alberta Environmental Protection, river user interest groups, the local health authority and a representative of the University of Alberta, to the technical process, and ensured that their input was considered in developing the plan. Newhouse et al. (1999a) described the development of a long-term CSO abatement plan by the City of Richmond, Virginia. The protection of recreational uses of the James River was a priority for the city. City officials at Richmond, Virginia, agreed to a joint venture with the Richmond Riverfront Development Corporation that would eliminate CSO and restore the Haxall/Kanawha canal system. Engineers not only had to ensure that each project's requirements and objectives were met, but also address technical and environmental issues without compromising the area's recreational and commercial needs or diminishing its aesthetic appeal or historic character (Newhouse et al. 1999b). Based on interviews conducted during 1998, Slack and Freedman (1999) compared and contrasted current state-to-state and community-to-community differences in efforts to control SSO. The variability in abatement efforts were tied into the proposed language for EPA's forthcoming Federal Register notice that will clarify NPDES requirements for municipal sanitary sewer collection systems and SSO.

Other authors addressed the steps taken to achieve CSO and SSO control. In the early 1990s, the City of Auburn, New York, was faced with the challenge of achieving CSO abatement and sanitary and interceptor sewer overflow (SSO) elimination in its extensive, aged sewer system and achieved their overflow abatement goals by: (1) quantifying and characterizing sewer overflows to provide a basis of design for abatement-related system improvements; (2) selecting a principal approach of conveyance of excess WWF to a centralized high-rate treatment facility for a majority of the sewer system; and (3) re-evaluating and applying alternative technologies to select portions of the sewer system to minimize project costs. Li and Banting (1999) presented a case study using a GIS planning tool for stormwater quality management in urbanized areas. The planning tool comprised five steps: (1) definition of stormwater retrofit goals and objectives; (2) identification of appropriate retrofit stormwater management practices; (3) formulation of stormwater retrofit strategies; (4) evaluation of Strategies with respect to retrofit goals and objectives; and (5) selection of stormwater retrofit strategies.

Markowitz et al. (1999) described the conceptual ideas, cost analysis and other issues that effect implementation of watershed controls within the scope of a CSO control plan. Osaka City's (Japan) major measures for improving CSO include: (1) leading as great a volume of pollutants as possible to WWTP in dry weather to avoid the pollutant accumulation in sewers; (2) storing first flush, which contains a large volume of pollutants, for treatment at WWTP after rainfall; and (3) treating WWF directly. Shiomi (1999) discussed the methods used to achieve these measures and reports the conclusions drawn from the cost-benefit analyses. A 5-year cooperative study of the Cumberland River at Nashville (Tennessee) allowed Nashville to alter its CSO control plan, eliminate two major detention tanks, and save $106,000,000. The study showed that neither DO depletion nor toxic material discharges were a problem, and that a fecal coliform bacteria problem would not be solved by planned detention tanks, or even by eliminating all CSO (Thackston and Murr, 1999). Today conventional planning and reconstruction of both the drainage network and the treatment plant for the same urban catchment was usually subdivided into two nearly independent parts. Walther and Rohlfing (1999) demonstrated optimal design of a combined sewer system and sewage treatment plant for a German city with 500,000 inhabitants by simulating the operation of both systems simultaneously, and costing each system based on a variety of possible configurations of the other.

Additional published accounts of the experiences of various municipalities in controlling CSO and SSO provide guidance for those beginning a WWF control program. The City of Auburn's (New York) sewer overflow abatement program summarized by Gorthey et al. (1999) can serve as a guide and source of information for other municipalities faced with achieving sewer overflow abatement. Igwe et al. (1999) focused on design and operational issues encountered during the evaluation of the Rouge River National Wet Weather Demonstration Program, which includes the construction of nine CSO detention basins of varying sizes and design. The City of Akron (Ohio) has successfully implemented the demonstration approach to CSO control and has supported controls that will result in measurable improvement of recreational use, aquatic life use and aesthetics of the receiving streams, including concepts other than traditional collection system alternatives. These include riparian setbacks in undeveloped areas, stream restoration, linear parks or greenways and artificial riffles for stream aeration. Merritt and Wilkinson (1999) presented studies on wastewater collection systems, including: collection system design and construction; wet weather control; infiltration and inflow; SSO; innovations in sewers and collection systems; infrastructure modeling; sewer pipe maintenance and rehabilitation; sediment transport, deposition and erosion in collection systems; and sustainable development. Protopapas (1999) reported the methodology used by New York City to abate pollution from CSO in the receiving harbor waters based on a case study for the East River facility planning. The approach integrates water quality studies, facility planning, environmental assessment and public participation. Wong and Nik-Hassan (1999) presented a case study that covers the planning, design and operation aspects of implementing a pumping drainage system into the existing drainage system at the Pasir Baru residential area in Kuala Lumpur (Malaysia) city. Zettler et al. (1999) discussed how the City of Fort Wayne, (Indiana) has successfully applied a consistent set of GIS-based information management tools to support both their CSO planning efforts and preliminary design process.

Innovative CSO controls - source controls. Innovative WWF control strategies include using rainwater and runoff for potable uses and controlling gaseous emissions from combined sewer systems. Herrmann et al. (1999) reported on a four-story apartment building which was renovated using an innovative water concept. Roof runoff used stored for use in flushing toilet, and excess runoff was infiltrated, allowing the building to be completely unconnected from the stormwater sewer. The authors showed that independent from the soil and the available space it was possible to restore the natural water balance again by combination of rainwater use and subsurface infiltration. Lausten et al. (1999) described the use of a biofilter to capture and control hydrocarbon odors including VOCs from a combined sewer and an interceptor sewer in Philadelphia, Pennsylvania. The biofilter has proven to be a successful process application for treating VOC compounds from the air stream. Lim and Lim (1999) described a unique scheme to implement urban stormwater pond collection systems for potable water use in Singapore. Close monitoring and control of pollution through the adoption of stringent anti-pollution measures and enforcement actions have resulted in the collection of generally good quality raw water from these urbanized catchments with very low levels of heavy metals and low coliform counts as compared to raw water from largely forested catchments.

Source control of WWF aims to reduce overflows by reducing inputs to the system. Schmitt et al. (1999b) described the correct procedures for inclusion of source control measures in urban stormwater management into the Gemnan design procedure A 128. Results obtained by long term pollution load simulations emphasized the need to review existing guidelines. Williams et al. (1999) reviewed a partnership between the Louisville and Jefferson County Metropolitan Sewer District (MSD), the Louisville Education and Employment Partnership (LEEP), and the Jefferson County Public Schools (JCPS) designed to provide an opportunity for students and teachers to work in a paid summer internship with consulting engineering firms that contract with MSD, and assist MSD in collecting information regarding wet weather issues such as misconnected downspouts, sump pumps, and leaky sanitary sewers. The program, which has been successful for five years, provides a quick and cost effective investigation that identifies inflow source reduction opportunities for mitigation of property damage and SSO.

Walesh et al. (1999) provided a discussion of the use of on-street storage as an effective means to control stormwater runoff and CSO in two communities in Illinois. This technology eliminated surcharging and basement flooding, complied with regulations, and proved to be a cost-effective solution which earned public support. Lachmayr and Schofield (1999) focused on the fieldwork techniques used to identify specific inflow sources from large buildings in the area served by the Boston Water and Sewer Commission, Massachusetts.

Tunnels and interceptors. Tunneling and interceptors play a role in WWF. The Columbia Slough Consolidation Conduit tunnel was a key element in alleviating CSO in Portland, Oregon. Rippe et al. (1999) described the design and construction of this soft ground tunnel project, with shallow ground cover and close proximity to an existing old concrete sewer, as well as the means of sharing risks between the owner and the contractor. Lannon and Roll (1999) described a challenging investigation of a deep tunnel interceptor blockage near the City of Niagara Falls (New York) that created persistent interceptor surcharging, prolonged upstream wet weather overflow following precipitation events, and an air release effect which propels wastewater over 27 meters (90 feet) upward from the interceptor through a drill hole during heavy rains. Roll (1999) described the diagnosis and restoration of diminished force main capacity in a wastewater transmission line linking the City of Niagara Falls, New York WWTP with its largest pumping station. The flow limitation reduced first flush capture from the combined collection system and occasionally resulted in manhole surcharging up to street level. Westoll (1999) described sewerage and sewage-treatment projects intended to control combined-sewer overflows that cause nuisance during rainfall in the town of Driffield (Yorkshire, England). The projects include a new interceptor, constructed using trenchless technology, and a four-basin cyclic activated-sludge plant.

Disinfection. Disinfection of CSO and SSO was practiced in many places. Stinson et al. (1999) discussed high-rate disinfection technologies for CSO, including ultraviolet light irradiation, ozone, chlorination/dechlorination, chlorine dioxide, peracetic acid, and high-voltage electron beam irradiation. Discussions of the technologies included commercial availability and extent of use, state-of-development when not commercial, and where available, performance data and cost of either full-scale or pilot-scale installation. Also discussed was utility of increased mixing in concert with any disinfection technology. In 1996, the Vallejo Sanitation and Flood Control District (California) replaced an outdated chlorine gas disinfection system with a state-of-the art medium pressure UV system, in combination with a liquid chemical system for use as backup during wet weather periods. Tekippe et al. (1999) reviewed VSFCD's three-year operating history, and presented a summary of startup and post-startup problems and their resulting solutions.

Litter and floatables. Riverine litter and floatables occupy a spatial and temporal position in any systematic analysis of river systems and represent a problem that was increasing in scale. Quantifiable source factors of litter in the river Taff, South Wales, United Kingdom, system were found to be mainly sewage inputs through CSO and fly tipping. Sewage-derived material constituted approximately 23 % of all items on the river, large quantities of waste, especially plastic sheeting, originated from fly tipping sites (Williams and Simmons, 1999). Burgess et al. (1999)

reported that the City of Indianapolis developed five CSO control facilities as "pilot" facilities, for the purpose of establishing and demonstrating the local suitability and effectiveness of the various technologies that they employ. Preliminary results, with emphasis on the capture characteristics of the floatable debris netting trap facilities, were presented. Bridgeport's (Connecticut) Water Pollution Control Authority has recently faced the problem of floating debris and the sound's high tide. These drainage problems have been successfully solved by building new flow-control regulators with integrated automatic radio (wireless) and telephone-modem (wired) control, water-flow, and instrumentation technologies (Morrill and Sound, 1999).

Real-time control (RTC). RTC of combined and sanitary sewer systems aims to reduce overflows by better utilizing the existing storage in a systems using real-time data such as rainfall and water level data to control adjustable weirs or pumps. Gonzalez et al. (1999) worked on the development and simulation of RTC systems for urban or metropolitan drainage systems with CSO or flood problems. They reported some conclusions and encourage the use of RTC systems on sewer systems. In response to floods in 1982, the Urban Community of Bordeaux decided to make improvements in their stormwater management system. Studies indicated that CSO have a significant effect on the environment. Therefore, emphasis will be placed on improving the management of the sewer system during rains and on the design of new storage structures and new treatment plants (Briat et al., 1999).

Artina et al. (1999b) presented an evaluation of the benefits given by different configurations of storage tanks in a virtual but likely urban pilot site. The study showed that RTC, even if always useful for the reduction of overflow volume and frequency, in some cases can increase the discharged loads, under the hypothesis of complete mixing without settling in tanks. Fuchs et al. (1999) described the results of a study of the potential of real-time control of CSO for the combined sewer system of the city of Dresden. The results showed a significant 5 % to 90 % (mean more than 35 %) reduction of the overflow volumes and loads for the controlled state compared to the uncontrolled one.

Villeneuve et al. (1999) presented a study of three types of RTC alternatives and conventional static control, applied to the Western section of the Quebec (Canada) Urban Community (QUC) sewer system. At the end of the long term CSO control plan it was projected that the QUC will control more than 85 % of the CSO, for a total cost of US $107,000,000 which was 37 % less than what had been estimated before the introduction of RTC. Risholt et al. (1999) reported on a project to document current discharges of pollutants and to find potential reduction by implementing RTC of the wastewater system in Fredrikstad, Norway.

Offline simulations carried out with a variety of control conditions suggest that great benefits were to be expected using global control with precise forecast information compared to a static system with local control only. Quirmbach et al (1999) presented an approach to joint operation of an urban drainage system and the corresponding sewage treatment plant. This operation was based on real-time flood forecasts, which were computed with the aid of radar rainfall measurements to minimize the combined negative effects of the hydraulic load (water quantity) and the pollution load (water quality) in the receiving waters during floods. Schmitt et al. (1999a) developed a new management strategy of the City of Nancy's sewage system (Lorraine, France) in order to reduce rainwater pollution overflows using a model which simulated flows in interceptors, transport of dissolved and solid pollutants, and precipitation, flocculation and sedimentation in WWTP. This new management strategy, optimizing the use of existing infrastructures, aims to conciliate flood risk management and the reduction of pollution overflows into the Meurthe River (France). Soeda et al. (1999) presented a case study of proposed improvements to combined sewer systems with no construction of new facilities and effective utilization of existing facilities through various modifications of stormwater pump operations. This system proved an effective means of reducing overflows and reducing pollutant loads from combined sewer systems.

Weib and Brombach (1999) examined the application, advantages, and hydraulic performance of devices for water level control like movable weirs (self-regulating or auxiliary powered) or siphons which were frequently used at overflow structures in urban drainage. Special focus was given to possible critical points and limits of application.Yagi and Sheba (1999) applied fuzzy logic control and genetic algorithms to achieve improved pump operations in a combined sewer pumping station. It was found that current pump operations can be improved by adding the sewer water quality to the input variables and to the fitness function; the improved operations can reduce not only floods in the drainage area but also pollutant loads discharged to the receiving waters.

CSO storage tanks and structures. Temporary storage at CSO and SSO outfalls, with effluent returned to the system for treatment when system loading subsides, was a widely practiced method of WWF control. Some authors focused on modeling and design of storage structures. Harwood and Saul (1999) described how the computational fluid dynamics software Fluent was used to simulate the hydraulic and particle retention efficiency performance of three extended stilling pond CSO chambers in the United Kingdom. It was concluded that where the effective retention of neutrally buoyant particles was a design criterion, increasing the size of the chamber may not be the most appropriate solution. Hobbs et al. (1999) discussed the use of flow equalization basins (FEB) for control of SSO and CSO. FEB increases systems capacity dramatically by retaining excessive flows until the collection system was better able to handle them and cost considerably less than more traditional methods. Maglionico (1999) proposes a methodology for the design of CSO tanks aimed to control first foul flush in sewer networks, based on a five years period of field continuous measurements carried out on rainfall, discharge and water quality in an experimental catchment near Bologna (Italy). Stovin et al. (1999) compared the results of simulated flow patterns and gross solids separation predictions with field measurements made in a full size storage chamber within an urban drainage system. Although estimates of total efficiency based on the observed settling velocity distribution differed from the measured values by an average of ±17 %, the simulated efficiencies agreed with the field observations in identifying the most efficient configuration. Van Mameren (1999) presented a method of using the results of rain series calculations as a design tool for stormwater sedimentation tanks, and demonstrated the method with an example.

Other papers presented case studies of CSO and SSO storage. For a better understanding of the spill over into the receiving waters, recorded data from 90 CSO tanks with a collective monitoring time of more than 300 years were compiled and analyzed by Brombach et al. (1999). A ranking procedure was proposed for an easy to handle evaluation of the overflow activity of CSO tanks. Hartshorne and Cadman (1999) described the design and construction of a 12,500 m^3 capacity stormwater storage tank in Westbourne Avenue, Rhyl (United Kingdom).The finished structure was completely buried and incorporates new pumping plant to pump dry-weather and storm flows.

Kearney and Schoetlle (1999) described methods of cleaning dewatered CSO-storage basins at the Spring Creek Auxiliary Water Pollution Control Plant, which was used for temporary storage and treatment of CSO in New York City. Murphy et al. (1999) report on an in-line CSO storage facility constructed of bolted together precast box culvert sections that was designed and built by local engineers and contractors in the City of Bangor, Maine. This inexpensive CSO storage option has numerous advantages over the alternatives. A cost-effectiveness analysis conducted by the City of Slidell, Louisiana demonstrated that an offline storage-facility would produce a substantial capital cost savings over multiple, decentralized line repair projects to achieve the same level of SSO control. The completed project applies commonly accepted technology to produce a system that worked within the funding constraints, was acceptable to the general public, and was easy to maintain for the operators (Prellop, 1999). Wada and Miura (1999) attempted to reduce CSO using a large-scale storage pipe, which was constructed for flood control. Using a movable diversion structure permitted use of the storage pipe for both flood control and CSO control.

CSO treatment. Another approach to CSO and SSO control was to treat the effluent before it enters a receiving water. Hufnagel et al. (1999) reported on the collection and analysis of data from six CSO demonstration facilities in the Rouge River watershed (Michigan) from June 1997 through September 1998, and discuss performance, operational experience, and insight gained on design of facilities from an operational perspective. Andoh et al. (1999) presented the results of testing of a novel self-cleaning CSO device at the United Kingdom National CSO Test Facility at Hoscar WWTP, Wigan, and concluded that CSO screening systems offering 4 mm two directional screening standard were significantly more efficient than 6 mm screens and might not entail any additional cost. Averill et al. (1999) described pilot-scale process development and full-scale demonstration work, and discussed considerations for the implementation of a high-rate physical-chemical treatment process that has been developed for use in satellite treatment systems to control CSO in Ontario, Canada.

Daligault et al. (1999) reported on two settling devices treating rainwater from urban drainage areas and equipped with secondary sludge treatment, which were monitored over a period exceeding one year. From analyses of the settled or extracted sludge it was possible to characterize the pollutants retained in the lamella settlers. To estimate the effect of enhancing settling in CSO storage basins by flocculation, a free growth and break-up model was developed and implemented by de Cock et al. (1999). Del Giudice and Hager (1999) discussed design and performance parameters for sewer sideweirs, which in a combined sewer system were used for diversion of excess discharge during rainfalls. Also discussed was the throttling pipe, which was a simple device to limit the discharge to treatment facilities. Dormoy et al. (1999) reported the results of a simulation of a WWTP with activated sludge, and concluded that it was advisable to allow for increased sludge production, O_2 requirements and also sludge quality (fermentability) when stormwater was treated. Faram and Andoh (1999) described the results of a program of numerical studies that were undertaken in order to assess and optimize the fluid-dynamic performance of a novel non-powered self-cleansing CSO screening system, the Hydro-Jet Screen™. Observations of the operation of both model and prototype scale units have indicated good qualitative correspondence with the predictions in terms of overall flow patterns, and have confirmed the superiority of the recommended design in terms of its self-flushing capabilities.

Green et al. (1999) examined the performance of constructed reed beds from a WWTP with storm treatment reed beds and another site with a combined storm and tertiary treatment reed bed. The results illustrated that sites with combined storm and tertiary treatment reed beds experienced a level of performance matching that of sites with tertiary treatment systems, with averages of 2.2 mg/L BOD_5, 3.0 mg/L TSS, 1.25 mg/L NH_4-N and 12.2 mg/L TON. Luyckx et al. (1999) compared the separating efficiency of an improved high-side weir overflow and a hydrodynamic Storm King™ separator. They show that when higher removal efficiencies were wanted, the hydrodynamic separator can technically as well as economically compete with simpler structures. The District of Columbia CSO Abatement Program included construction of a 400-MGD swirl concentrator at the outfall of the District's Northeast Boundary combined sewer; an outfall responsible for approximately 50 % of the total CSO from the District. Extensive pre- and post-construction monitoring of instream DO concentrations up and down stream of the outfall indicate that the separator has had a dramatic impact on DO concentrations downstream of the outfall; cumulative frequency analyses indicate virtually no difference in DO concentrations between the upstream and downstream meters since the swirl concentrator went online (Murphy et al., 1999). The problems created by sediment deposits in combined sewer systems (sanitary and storm) include a loss in conveyance due to these deposits which contributes to hydraulic overloading, leading to flooding, premature operation of CSO, and the washout of sediments through CSO into urban watercourses during times of storm. Vaes and Barlamont (1999c) discussed the implications of new design and analysis techniques and combinations of new and older components in combined sewer systems based on an evaluation of the various approaches and technologies used over the last eight years in Flanders, Belgium.

Detention/Retention Ponds

Current stormwater quality control pond design in Ontario, Canada typically includes the specification of a uniform detention time for extended detention ponds to ensure water quality control. In reality, the pollution-control performance of such facilities was governed by two opposing forces: improved pollutant removal efficiency over longer detention times and the decreased volume of runoff captured and treated by the facility for longer detention times (Papa et al., 1999).

Three seasonal surveys of suspended solids were carried out in an on-stream stormwater management pond, by means of a submersible laser particle size analyser. Size distributions were measured at up to 17 points in the pond, and water samples collected at the same locations were analysed for primary particles aggregated in flocs. Using a relationship defining the flee density as a function of flee size and Stokes' equation for settling, an empirical relationship expressing the free fall velocity as a function of floc size was produced (Krishnappan et al., 1999). Jacopin et al. (1999) examined the new operational management practices for detention tanks, with grassed banks and bottom installed on a separate stormwater network, during rainfall events in order to limit flooding risk and, at the same time, to reduce pollutant discharges by optimising the settling process.

Use of stormwater retention and detention basins has become a popular method for managing urban and suburban stormwater runoff. Infiltration of stormwater through these basins, however, may increase the risk to ground-water quality, especially in areas like the Coastal Plain of southern New Jersey, where the soil was sandy and the water table shallow, and contaminants may not have a chance to degrade or sorb onto soil particles before reaching the saturated zone. Ground water from monitoring wells installed in basins in Camden and Gloucester Counties, New Jersey, was sampled and analyzed for volatile organic compounds (VOC), pesticides, nutrients, and major ions

(Fischer, 1999). Crunkilton and Kron (1999) measured the toxicity of stormwater runoff before and after it had been allowed to flow through a pilot-scale wet-detention basin. Selected heavy metals and PAH compounds were measured in incoming and outgoing-settling basin water. *Daphnia magna* and *Pimephales promelas* (fathead minnow) were exposed to pre and post-settling basin treated stormwater runoff for three test periods of 14 days each in 1996 and 1997.

Stormwater reuse has been incorporated into the design of wet-detention systems constructed in Florida. Stormwater reuse reduces the volume of stormwater discharged downstream thereby decreasing the loss of potentially valuable freshwater resource. Additionally, by reusing the detained stormwater instead of discharging it, the treatment efficiency of the stormwater detention pond was increased thereby decreasing the pollutant load delivered downstream (Livingston, 1999). The suitability of treatment ponds for mitigation of chemical contaminant loads and toxicity was investigated under baseflow conditions in two systems serving urban and industrial catchments (Hickey, 1999).

Multiple drainage objectives. Wada et al. (1999) investigated the possibility of using a storage tank or pond, for both flood control and stormwater control. They found that the first flush could be directed into an initial storage area, while peak runoff flows could be directed to a secondary storage area. The suitable storage volume of the first pond would be 1-2 mm of runoff and the secondary pond volume would be 3-4 mm of runoff. Cabot et al. (1999) also described the dual use of ponds in Barcelona, Spain, where several detention facilities have been designed to simultaneously address both flooding and CSO. The design procedure has been validated with a detailed model, and a simplified rule has been developed stressing the use of the 10-year design storm. The 100-year design storm was then used to obtain the design capacity of the overflow structures of the facilities. Drainage objectives in Belgrade, Yugoslavia were to separate stormwater from wastewater in areas of existing combined systems and to limit peak discharges by means of detention ponds in the upstream part of the drainage areas for downstream flood prevention (Despotovic et al., 1999).

Pond sizing. Guo (1999) described a simple method to size stormwater detention basins using a volume-based method such as provided by the Federal Aviation Administration that was applicable to small urban catchments. The average outflow from the detention basin (the most important aspect affecting reliability) was found to be related to the time of concentration of the catchment and the duration of the design storm. Guo and Adams (1999a) described how the flow-capture efficiency and average detention time (the performance measures commonly used in assessing the long-term pollutant removal effectiveness of stormwater detention ponds) can be statistically estimated. Guo and Adams (1999b) further described the analytical probabilistic approach that can be used for evaluating designs of detention facilities that was a computationally efficient alternative to continuous simulation. Papa et al. (1999) described how the pollution-prevention performance of detention facilities was governed by two opposing forces: improved pollutant-removal efficiency over longer detention times, and the decreased volume of runoff captured and treated by the facility for longer detention times. The combination of these effects produces a maximum attainable level of long-term pollution-control performance at an optimal detention time. Harston and Joliffe (1999) described the recent New South Wales (Australia) stormwater management manual which has identified three different classifications for sediment basins. Type F and Type D basins were designed for total containment of runoff and discharge after a predetermined time period to allow efficient containment and release after flocculation to settle the fine sediments.

Locating detention facilities in older areas. Rivard and Dupuis (1999) described how older drainage systems, especially combined sewers, that frequently experience hydraulic surcharges can sometimes be improved by restricting the inflows at the inlets, causing a limited retention of stormwater on the streets. Scott et al. (1999) examined both onsite detention and on-site retention for a set of hypothetical urban catchments ranging in size from 14 ha to 210 ha. The objective was to achieve the same peak flow rate reduction at least cost. The onsite retention facilities was shown to out-perform the detention in most of the medium to large catchments.

Modeling pond performance. Hollingwork et al. (1999) also presented an analytical probabilistic model (MTOPOND) that used probability distribution functions of rainfall characteristics in order to develop closed form expressions for the long term pollutant removal efficiency of stormwater ponds. Operational management practices for detention facilities to limit flooding risks simultaneously with reduced pollutant discharges was possible by optimizing the settling process, as described by Jacopin et al. (1999a). They found that proper descriptions of the particle sizes were critical and that the particle size distribution in the surface sediments were close to those of the suspended solids in the stormwater. Jacopin et al. (1999b) further described the optimization process where the detention facilities were empty most of the time, offering a large safety margin to protect against flooding. The detention facilities store all of the runoff from light and medium rainfall events, consuming about half of the detention capacity. The probability of exceeding the tank capacity was small, even for the larger storms. Adamsson et al. (1999) found that computational fluid dynamics (CFD) was a good tool for studying the hydraulic properties of detention basins in urban drainage systems.

Observed pond performance. Petterson et al. (1999) studied the pollutant-removal efficiency of two stormwater ponds in Sweden. Observed outflow pollutant conditions were independent of the influent conditions for the two ponds. They also found that pollutant removal efficiency increased for increasing values of ratio of the pond surface area to the watershed impervious area, up to about 250 m^2/ha, while the benefits of larger ponds were not as important. Bartone and Uchrin (1999) compared the performance of two dry-stormwater-detention facilities, one having a concrete low-flow channel, and the other with a vegetated low-flow channel during four events. As they expected, the detention pond having the concrete channel was ineffective for stormwater quality control. However, the basin with the vegetated channel was also found essentially ineffective for water quality improvement, with flushing of previously captured pollutants being the most likely reason for the poor performance. The retention of heavy metals in a wet reed-bed wetland were compared to retention in a dry-detention pond near London, United Kingdom, by Hares and Ward (1999). A higher percentage removal occurred in the monitored wetland facility than in the dry pond. Shatwell and Corderly (1999) examined nutrient removals in a pond in Sydney’s (Australia) Centennial Park that receives stormwater from a 120 ha catchment that was predominantly residential. They found significant amounts of phosphorus and sediment accumulating in the pond, especially during the small- to medium-sized rain events (approximately 60 % phosphorous and 80 % suspended sediment reductions).

Krishnappan et al. (1999) monitored in-pond particle sizes using a submersible laser particle size analyzer, reducing potential changes in particle characteristics that may occur during sampling. The suspended solids were mostly composed of flocs, and were about 30 µm in size during winter surveys and about 210 µm during the summer surveys. MacDonald et al. (1999) investigated the removal of heavy metals in a detention pond in Scotland. They found that the sediment in the pond may reach unacceptable concentrations of heavy metals within twenty years. Petterson (1999) examined the partitioning of heavy metals in particulate-bound and dissolved phases in a stormwater pond in Goteborg, Sweden. The results showed a clear variation in lead partitioning affected by specific conductivity.

Problems observed with stormwater ponds. Beyerlin (1999) described the short-comings of relying on stormwater-detention facilities for complete mitigation of urban runoff problems. Increased winter flood flows, decreased summer low flows, and a general degradation of the stream systems has occurred with development. It was concluded that these problems persisted because of the attempt of replacing the complex interactions of the hydrologic cycle with a pond, which was not possible. Brown et al. (1999) described the degradation in quality in Sydney (Australia) Centennial Park's ponds over the past 150 years. Pond rehabilitation techniques have been developed and were being implemented, based on wetland principles.

Wetlands

According to Koob et al. (1999), the successful design of constructed wetlands required a continuous supply of water or vegetation that can withstand drought conditions. Detention structure designs should be based on times between events as well as on hydrologic return periods, since between events was when most evaporation and infiltration losses were likely to occur. Serrano et al.(1999) investigated phosphorus (P) concentrations in Donana seasonal wetlands in southwestern Spain as the wetlands started to fill following storm events after a drought. NPS N from riverine origin was a major water quality problem throughout the world. Hunt et al.(1999) reported that total annual N removal for the in stream wetland was approximately 3 kg/ha per day, which was about 37 % of the inflow N. Removal of both NO_3-N and total N (NO_3-N + TKN) were positively correlated to temperature with r-values of 0.77

and 0.62, respectively. According to Zhu and Ehrenfeld (1999), the presence of urban and suburban lands adjacent to wetlands may cause changes in nutrient-cycling processes, due to changes in the quality of the ground and surface waters that drain from the developed uplands into the wetlands. The alternations in hydrology and the input of mineral-rich sediments, in addition to excess N from the septic drainage and road runoff, can apparently cause increases in N mineralization within the wetland sediments, thus exacerbating the direct deleterious effects of roads and housing on water quality. Quantitative estimates of denitrification were needed in designing artificial wetlands to optimize nitrate (NO_3^-) removal. Acetylene blockage and N-15-tracer methods were employed to quantify denitrification in constructed wetlands receiving agricultural tile drainage, using plastic tubes to enclose in situ mesocosms. Because water infiltration carries NO_3^- through the anaerobic sediment/water interface for denitrification, a subsurface-flow wetland may denitrify more NO_3^- than a surface-flow wetland (Xue et al., 1999).

According to Guardo, (1999) the Everglades Nutrient Removal (ENR) Project, a 1544-ha wetland, was designed and constructed as a pilot project to gain experience on design, construction, and operation of the stormwater treatment areas. For the 732 days analyzed (19 August 1994 through 19 August 1996), the average water inputs into the project were as follows: 86.2 % from the inflow pumps, 11.2 % from rainfall, and 2.6 % as emerging measured and estimated seepage from an adjacent area with higher stages; the average water outputs from the project consisted of 85.1 % from the outflow pumps, 8.9 % as evapotranspiration, and 6.0 % as a net seepage and groundwater component. The ENR Project's purpose was the removingof nutrients (especially phosphorus) from agricultural drainage and stormwater runoff before entering the Everglades. The hydrology and water quality of an urban wetland receiving stormwater runoff from a municipal maintenance garage were measured during the summer of 1993 to evaluate the wetland's water quality enhancement function. According to Thurston (1999), hydrologic and analytical data together suggest that sedimentation was the primary mechanism actively reducing water column concentrations of lead and petroleum hydrocarbons introduced to the wetland via stormwater runoff.

It was evident that existing designs for the control of highway discharges were primarily if not exclusively intended to control runoff volumes rather than as any complementary pollution treatment function. However, regulatory pressures on highway authorities and agencies were increasingly requiring that drainage controls should include reference to water quality treatment and the clear inadequacy of conventional drainage systems has stimulated interest in the design, implementation and operation of alternative vegetative systems, such as swales and wetlands (Ellis, 1999a and 1999b).

To address the unknowns and design concerns of a stormwater wetland system, a bench-scale vegetative-treatment-cell study has been conducted for the purpose of examining nutrient and metal dynamics and removal efficiencies of three individual plant species under various stormwater-pollutant loadings and detention times. The plant species being evaluated are: cattails (*Typha latifolia*), reeds (*Phragmites sp.*), and bulrushes (*Scirpus sp.*) (O'Shea et al., 1999). The design and pollutant removal performance of seven wetland mitigation sites and two detention basins with emergent vegetation in Virginia were examined over a three-year period to assess the effectiveness of mitigated wetlands for the control of NPS pollution and the influence of design on wetland performance as a BMP, in a study sponsored by the Federal Highway Administration and the Virginia Department of Conservation and Recreation (Shaw et al., 1999). The Tollgate District Sewer Separation Project involved the separation of a combined sewer system, and the creation of a wetland detention basin. In addition to its stormwater detention uses, the wetland serves as a wildlife refuge, learning center, and a local point of public outreach to bring the community together (Lindemann, 1999).

Design guidelines. Koop et al. (1999) stress that the successful design of constructed wetlands requires a continuous supply of water for vegetation to withstand drought conditions. They acknowledge that there were drought tolerant species of vegetation that can be used in constructed wetlands, however, it can take several days to re-establish the attached bacteria communities that were necessary for optimum pollutant removal. Lawrence and Breen (1999) described new design guidelines for constructed wetlands. They also highlighted some areas where further information was required to facilitate a more rigorous analysis of wetlands to optimize their selection, design, and assessment. Lawrence (1999) described a generic pond and wetland model that can provide water quality assessments for a range of geographic areas and information needs.

Persson et al. (1999) examined the hydraulic efficiency of constructed wetlands. They found that proper control of the hydrologic regime of the wetland and optimal flow hydrodynamics within the wetland were necessary for their sustainable operation. They concluded that many of the problems encountered in constructed wetlands can be minimized, or avoided, by good engineering design principles, including optimizing their shape and layout. Rash and Liehr (1999) also looked at the flow patterns within a constructed wetland near Wilmington, North Carolina, using lithium chloride tracers. Short-circuiting was common in subsurface-flow wetlands, while vegetated free water surface wetlands were well-mixed and not as subject to short-circuiting.

Wetlands for CSO. Liebig, *et al*, (1999) described the stochastic behavior of hydraulic and pollutant loadings of constructed wetlands for CSO and stormwater treatment. A comprehensive three-year monitoring program of a constructed CSO wetland in Kamen-Methler, Northrhine-Westfalia, Germany, was undertaken to monitor the pond's effectiveness and to establish planning, design and operation guidelines. Wong et al. (1999c) reported on the performance of the Braunebach research wetland in Germany and described the suitability of a two-parameter first-order-decay model for predicting the performance of the constructed wetlands for the treatment of CSO. A total of 30 CSO events were monitored and the results demonstrated the suitability and reliability of this model for SS, BOD_5, total phosphorus and soluble reactive phosphorus. The Fulda Fellenweg wetland system, also in Germany, was built in 1992, and consists of a 550 m^2 soil filter planted with reeds, and a basin with a detention volume of 786 m^3. Born (1999) described the performance of this system in treating CSO. The efficiency of the system was about 90 % for COD, NH_4-N, SS and PO_4-P and the removal efficiencies were independent on the resident times in the system. The permeability did not decrease during the five-year monitoring period. The main design parameter for the system was the surface loading rate (usually about 0.011 L/m^2-s). Faster rates (up to 0.027 L/m^2-s) showed only a negligible decrease in performance.

Observed wetland performance. Guardo (1999) examined the nutrient removal ability and the hydrologic balance of a wetland located in South Florida over a period of two years. A 1540 ha wetland was constructed as a pilot project as part of a major study investigating methods to reduce nutrient discharges into the Everglades. Hunt et al. (1999) studied nitrate removals in a wetland located in North Carolina. The average concentrations were reduced from 6.6 to 2.0 mg/L. Nitrate mass removals were highly correlated to inflow concentrations in the warmer months when biological processes were more active, while the ammonia mass removals were highly correlated to inflow ammonia concentrations during the cooler months. Moustafa (1999b) described monitoring results from Boney Marsh, Florida. Water-loading rate, water depth, phosphorus-loading rate, and water-retention time were examined for their influence on phosphorus removals. A simple quantitative diagram was developed that related these factors to phosphorus removal. White (1999) described the performance of a small wetland, located near Mobile, Alabama, for reducing suspended solids and nutrients in stormwater. The wetland system was constructed in January 1996 and monitoring results have shown that suspended solids and total phosphorus removals were significant (up to 90 %), but that nitrogen removals were much less (about 20 %).

Bacteria removal rates in a marshland upwelling system were reported by Rusch et al. (1999). Fecal coliform (FC) bacteria analyses indicated reductions from an average influent value of about 1 500 FC/100 mL to an average of 2 FC/100 mL in 5-foot deep monitoring wells. A filtration model predicted that the k value for the first order removal reaction was 0.40 – 0.56/d and that the predicted content of FC in the wetland surface was near zero.

Scholes et al. (1999) described the performance of two wetlands located near London, United Kingdom. Removal efficiencies were greater than 65 % for Zn, Cd, Pb, and Cu, at one site, while they were only about one-half of these rates at the other site. They also investigated the role of microorganisms in removing the heavy metals and two metal tolerant strains were found to accumulate Pb and Zn. It was believed that this ability may prove to be an important year-round pollutant removal process. Lead and petroleum hydrocarbons (originating from a municipal public works yard) were monitored in an urban wetland by Thurston (1999). Levels of these compounds in the sediments were higher near the inlet than elsewhere. It was concluded that sedimentation was the primary mechanism responsible for reducing the concentrations. Dombeck et al. (1999) examined the assimilation of trace metals in wetland sediments at the Sacramento (California) Regional County Sanitation District's Constructed Wetland Demonstration Project. Six metals (silver, cadmium, copper, mercury, lead and zinc) consistently exceed mass removal rates of 60 %. Chromium and nickel were observed in concentrations approaching or exceeding the freshwater sediment Probable Effect Levels (PEL). It was expected that the nickel enters the wetland in a predominantly dissolved and strongly organic-complexed form.

Problems in wetlands. The aquatic plant community was found to dramatically degrade in an urbanizing wetland study area located in Portland, Oregon, during studies by Magee et al. (1999). They were concerned that current wetland management practices were replacing natural marshes and wet meadow systems with ponds, further resulting in changes in the composition of the plant species assemblages. Revitt et al. (1999b) studied the pollutant removal at two constructed wetlands. The behavior of suspended solids was the greatest concern, as higher outlet concentrations were consistently discharged compared to inlet conditions, presumably due to re-suspension.

Russell (1999) was very concerned about artificial wetlands providing suitable habitats for mosquitoes in Australia. The Ross River virus, spread by mosquitoes, was of special concern as it was responsible for thousands of cases annually of a disease that was severely debilitating. It was suggested that mosquito control should not rely solely on chemical and biological agents, but that the design parameters of wetlands can also be important. Shallow water and dense vegetation promote mosquito production, while deeper habitats with cleaner steeper margins, and more open water, produce fewer mosquitoes. Aeration and fountains can reduce larval densities and vegetation thinning can assist mosquito predators.

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